

Naval Research Laboratory

Washington, DC 20375-5320

AD-A257 161



NRL/MR/6180-92-7145

## Findings of Portable Air Mover Tests on the ex-USS SHADWELL

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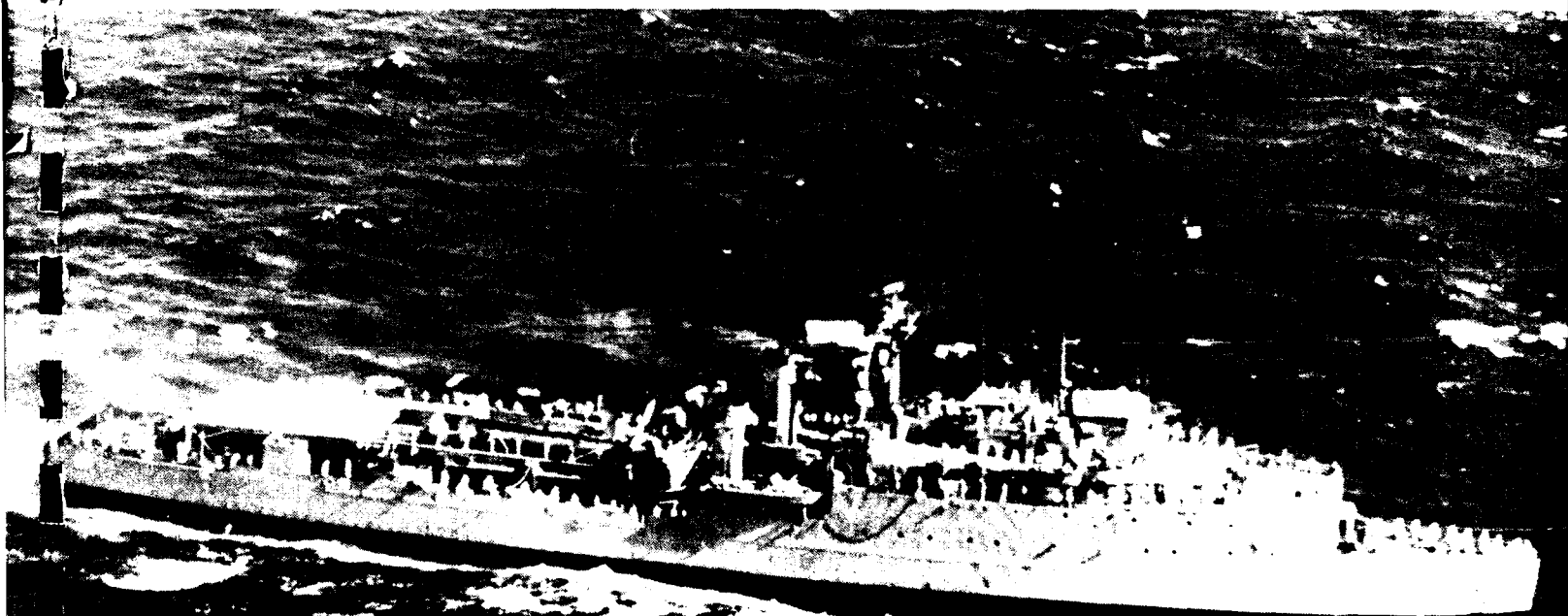
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Chemistry Division*

September 30, 1992

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# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE September 30, 1992		3. REPORT TYPE AND DATES COVERED Oct-Nov 1990	
4. TITLE AND SUBTITLE Findings of Portable Air Mover Tests on the ex-USS SHADWELL				5. FUNDING NUMBERS PE - 63514N PR - S1565-SL TA DC02FFS-03	
6. AUTHOR(S) J.T. Wong,* T.A. Toomey,* F.W. Williams, B.J. Havlovick,* and J.L. Scheffey*					
7. PERFORMING ORGANIZATION NAME(S) and ADDRESS(ES) Naval Research Laboratory Washington, DC 20375-5320				8. PERFORMING ORGANIZATION REPORT NUMBER NRL/MR/6180-92-7145	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Sea Systems Command Washington, DC 20362				10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES *Hughes Associates, Inc., Columbia, MD 21045					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  A series of full-scale desmoking tests were conducted to determine the effectiveness of a candidate water motor-driven, portable air mover. These tests were conducted on board the NRL fire research vessel, ex-USS SHADWELL. The water motor fan, when operated at design fire main pressures, was superior to other desmoking equipment tested. The performance of existing electric powered desmoking fans could be improved by increasing the size of the ventilation ducting. Supplemental tests demonstrated the ability of the water motor fan to perform when subjected to varied operating conditions. The use of desmoking equipment in combination with smoke curtains was demonstrated. Specific hardware recommendations and draft guidance for the development of tactics and procedures for the water motor fan are described.					
14. SUBJECT TERMS  Water motor driven fan      Desmoking      Ventilation Shipboard firefighting      Smoke curtains      Smoke control				15. NUMBER OF PAGES 523	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL		

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## **FINDINGS OF PORTABLE AIR MOVER TESTS ON ex-USS SHADWELL**

### **1.0 BACKGROUND**

Smoke removal, venting and control issues were identified in the USS STARK Post-Fire Damage Analysis [1]. These issues included the number and capacity of smoke removal equipment, and power requirements (additional extension cords for Red Devil Blowers). The Damage Control/Fire Fighting Working Group has identified the need to compliment or replace the Red Devil Bower with a maintenance-free fan which can be handled by a single person [2]. An improved fan would remove smoke at a rate equal to or greater than the existing blower, would operate within available shipboard power supply capabilities (water pressure in the case of water motor fan), and would be highly reliable and easy to maintain. Relatively easy modifications to the Red Devil fan might also be made to improve the capacity of that fan. As a result, commercially available desmoking fans driven by water motor turbines were selected for Navy use.

Three candidate water motor fans that met preliminary NAVSEA requirements were tested by Southwest Research Institute (SWRI). The units selected for testing were the following:

- Typhoon III, Model 10TFN,  
Manufactured by Hale Fire Pump Company,  
Conshohocken, Pennsylvania;
- RAMFAN 2000, Model WF-20,  
Manufactured by RAM Centrifugal Products, Inc.,  
National City, California; and
- Spritznas Model 8-1610-0400 Axial Flow Fan,  
Manufactured by Spritznas Maschinenfabrik GmbH of Langenberg,  
Germany,  
Distributed domestically by COB Industries of Melbourne, Florida.

Operational tests included air flow performance of the fans in different orientations, e.g. vertical (i.e., 90° from horizontal), continuous operation using brackish water and a drop test [3]. The following is a summary of results compiled from SWRI's report which disqualified or qualified the fans.

Fans			
Operational Test	RAM	Hale	COB
Air Flow Performance	Produced highest air flow rate and discharge pressure for a given water supply	Next highest air flow rate after RAM	Maximum air output below NAVSEA minimum requirements
360 Hour Endurance using brackish water	Minor corrosion to turbine housing but did not affect blower performance	Cavitation and corrosion to water turbine which eventually rendered fan inoperable	Water turbine and fan drive shaft seal leaks
Drop Test	Superficial damage to blower handle but did not affect blower performance	Damage to framework which prevented hoses from being properly connected or disconnected	Blower housing bent out of round which made attaching ducts difficult. Also housing at the fan suction and discharge end bent thus blocking air flow.
Size and Maneuverability	Smallest and easiest to carry.  Low center of gravity—it was the stablest of the three fans	Second smallest.  Could be carried by 1 person but 2 were needed for storing overhead.  High center of gravity—it had a tendency to tip.	Largest of the three fans.  Required 2 people to transport.

Based on SWRI's results, only the RAMFAN was evaluated against real fires, i.e., desmoking capability, heat stress, and operational factors. Since the original test plan called for the evaluation of three fans and only one passed the SWRI tests, the test plan was revised to address fire fighting operational factors and additional doctrine and tactics. The Red Devil was tested to provide a baseline comparison for evaluating the RAMFAN. This comparison included existing doctrine and tactics for the Red Devil. In addition, a simple modification to the Red Devil to increase capacity was also assessed during these tests.

## 2.0 OBJECTIVES

The objectives of these tests were to quantitatively evaluate the performance of a commercially available water driven turbine fan when subjected to a shipboard fire environment. A qualitative assessment of the applicability of the device for shipboard use was also made. This assessment included the ease of handling of the fan, time to install the fan, design improvements/modifications, and personnel and training suggestions. This information will supplement the concurrent Fleet evaluation of the devices. Possible improvements to the Red Devil were also investigated. At present, the Red Devil is only capable of using 20.3 cm (8 in.) supply and exhaust ducts.

Smoke curtains were used to contain the smoke in the compartments. Ways of improving the fan's desmoking ability were investigated through the use of smoke curtains in conjunction with the desmoking fans.

## 3.0 APPROACH

The Internal Ship Conflagration Control (ISCC) fire test area on the port wing wall of the ex-USS SHADWELL was used for these tests. The ISCC Fire Dynamics Test Plan provided the basic fire test plan and instrumentation layout [4]. Background

burns were conducted to characterize heat/smoke spread in areas adjacent to the fire compartment and to assess possible design fires for the air mover tests.

The two basic design fires used in this test series were a heptane pool fire and a diesel spray fire. The heptane pool fires provided the basic flow pattern of the smoke and was used to show the water motor fan's (WMF) capability to remove smoke. Spray fires were used to investigate the WMF's desmoking performance when a large volume of smoke was present.

Both design fire types were conducted in the unmanned and manned scenarios. Manned evolutions were used to determine the ease of handling of the fans. Sections 7, 8, and 9 offer more detail on the scenarios, setup, and procedures.

The effectiveness of the candidate water motor fan was measured by smoke and heat reduction compared to desmoking by the existing Red Devil Blower. In judging the performance of the water motor fan, thermocouples, smoke meters and gas analyzers were used to measure the reduction of heat, smoke and gas concentrations and oxygen recovery. To further evaluate the water motor fan under shipboard environments, the fan was tested under various water pressure supplies, and extended heat exposures. The time to place the fan unit into service was an additional criterion in judging the fans.

A supplementary water mist test was conducted to determine the plausibility of using the WMF for cooling. The WMF's potential use as a tool for gaining access to hot compartments was assessed by measuring the bulkhead and compartment air temperatures with thermocouples. The internal water spray nozzle on the RAMFAN was used during a fire test. A separate water mist test was conducted with the Hale Typhoon III to assess its performance.

The tactical procedures for implementing smoke curtains in conjunction with desmoking fans were explored. This was done by varying the location and the amount of supply make-up air. Mechanical desmoking is dependent on the amount of

make-up air available to the smoke-filled area. Without fresh make-up air, mechanical extraction of smoke is highly inefficient.

#### **4.0 TEST FACILITY AND PERSONNEL**

These tests were conducted on board the ex-USS SHADWELL at the Naval Technology Center for Safety and Survivability, Mobile, AL. Fire tests were performed in the port wing wall between FR 60-80 (Fig. 1). BERTHING 2 was the burn area. BERTHING 1 and RICER 1 were the compartments used to measure desmoking effectiveness. Tests were conducted between 15 Oct. and 2 Nov., 1990.

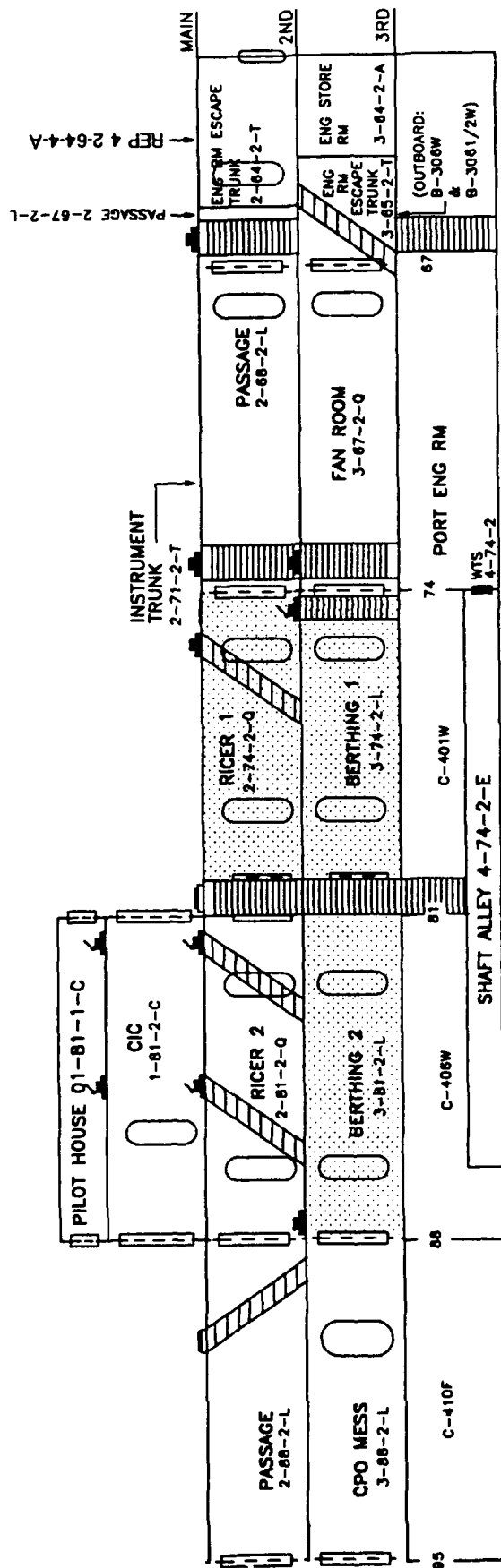
Senior enlisted personnel from the Fleet Training Center Fire Fighting School, Norfolk were used as fire fighting experts for desmoking evolutions. After each test, they were debriefed by test personnel to obtain qualitative data on setup, tactics, and equipment improvements. The ship's operational status during the tests was LEVEL IIa [5].

#### **5.0 EQUIPMENT**

##### **5.1 Fan Equipment**

The two fans used for desmoking in this test series were the RAMFAN 2000, (a water-driven motor fan) and the Red Devil Blower, which is driven by an electric motor. The following specific equipment was used:

1. Red Devil Blower, 0 1/2 1X flow type (NSN 4140-00-267-0967) with 20.3 cm (8 in.) diameter ventilation hose (Fig. 2);
2. Red Devil Blower, with adapters to use the RAMFAN 25.4 cm (10 in.) diameter ventilation hose (Fig. 3); and



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Fig. 1 - Section view of ex-SHADWELL port wing wall,  
ISCC test area, used for air mover tests

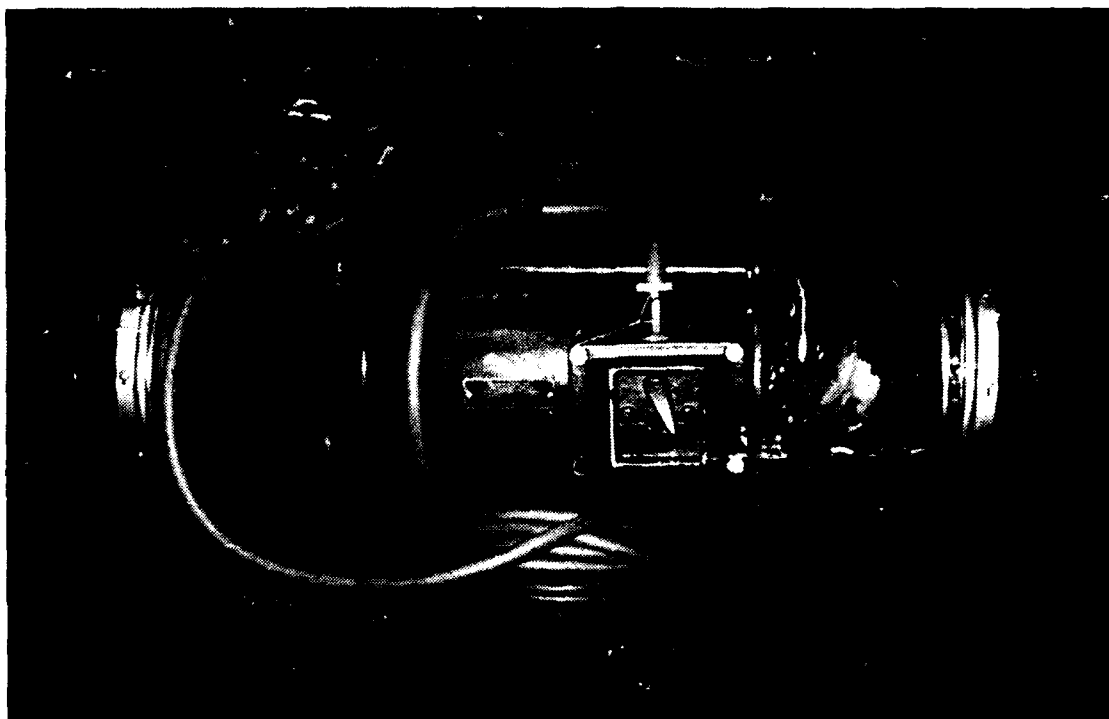


Fig. 2 - Red Devil fitted with 20.3 cm (8 in) ducts





Fig. 3 - Adapters for Red Devil to use 25.4 cm (10 in) ducts

3. RAMFAN 2000, Model WF-20, water motor-driven portable blower manufactured by RAM Centrifugal Products, Inc. with 25.4 cm (10 in.) diameter ventilation hose (Fig. 4).

The RAMFAN 2000, which passed the preliminary tests at SWRI, is designed as a high head (38.1 cm H<sub>2</sub>O (15 in. H<sub>2</sub>O)), high capacity (57 m<sup>3</sup>/min (2000 cfm)) fan for removal of smoke and other hazardous gases. The fan is powered by pressurized water with an operating range from 40 to 180 psi. The operating speed is dependent on the inlet and outlet water pressure and length of air duct attached.

The pressurized water is supplied to the turbine inlet swivel fitting through a 3.8 cm (1.5 in.) fire hose. The water passes through the turbine and out through the discharge swivel fitting with a 3.8 cm (1.5 in.) fire hose adapter. The inlet swivel is fitted with an inlet strainer made of stainless steel wire cloth. The strainer is positioned between the swivel and a double female adapter. The adapter allows attachment of a 3.8 cm (1.5 in.) NPSH male hose fitting. The discharge swivel is configured to accept a 3.8 cm (1.5 in.) NPSH female hose fitting.

The RAMFAN 2000 weighs 15.9 kg (35 lbs) and can be carried by a single person. It is designed to allow access through a 45.7 cm (18 in.) opening. The fan housing is constructed of a chemical-resistant aluminum and is designed to be explosion-proof. The critical components in the turbine are made of an abrasion-resistant plastic designed to resist corrosion and erosion. The shaft and fasteners are made of stainless steel [6].

The RAMFAN is capable of handling duct sizes of 20.3 cm, 25.4 cm and 30.5 cm (8 in., 10 in., and 12 in.). The wire/fabric ducts supplied were 457.2 cm (15 ft) long. The suction duct has a double wire coil while the exhaust duct has only a single wire coil. The double wire coil is designed to prevent the suction duct from collapsing while it is exhausting an area.



Fig. 4 - RAMFAN with the 25.4 cm (10 in) ducts

The Red Devil Blower (NSN 4140-00-267-0967) weighs 498 kg (109 lbs). It is an axial flow-type blower that is fitted with a 20.3 cm (8 in.) diameter, non-collapsible duct. The rated capacity of the Red Devil is 14.2 m<sup>3</sup>/min (500 cfm). The blower is driven by a 110 volt electric motor [7].

## 5.2 Test/Fire Fighting Equipment

The following test equipment was used:

- A Hale Typhoon positive pressure fan (89 cm (35 in.) in diameter),
- P-250 pump, MOD1, and
- Smoke curtains.

The Hale Typhoon water-driven fan was used to supply combustion air from the aft compartment to BERTHING 2 (FR 88) for the desmoking tests. A drum cowling was attached so the airflow could be directed into Berthing 2. A smoke curtain enclosed the area around the cowling (Fig. 5).

The following fire fighting equipment was used to extinguish any remaining flames after a fire test:

- 1.91 cm (0.75 in.) hose line with spray nozzle, and
- CO<sub>2</sub> extinguishers.

For the water misting tests, the following equipment was used:

- RAMFAN 2000, Model WF20, with a Bete TF10N (50°) spray nozzle and a detachable cone made of 0.32 cm (0.12 in.) polypropylene at the discharge side of the fan (Figs. 6 and 7), and a
- Hale Typhoon III, Model 10TFN, equipped with an integral spray nozzle (Fig. 8).



Fig. 1 Typhoon fan with drum cowlings used to supply combustion air to BERTHING 2



Fig. 6 - RAMFAN with the integral spray nozzle

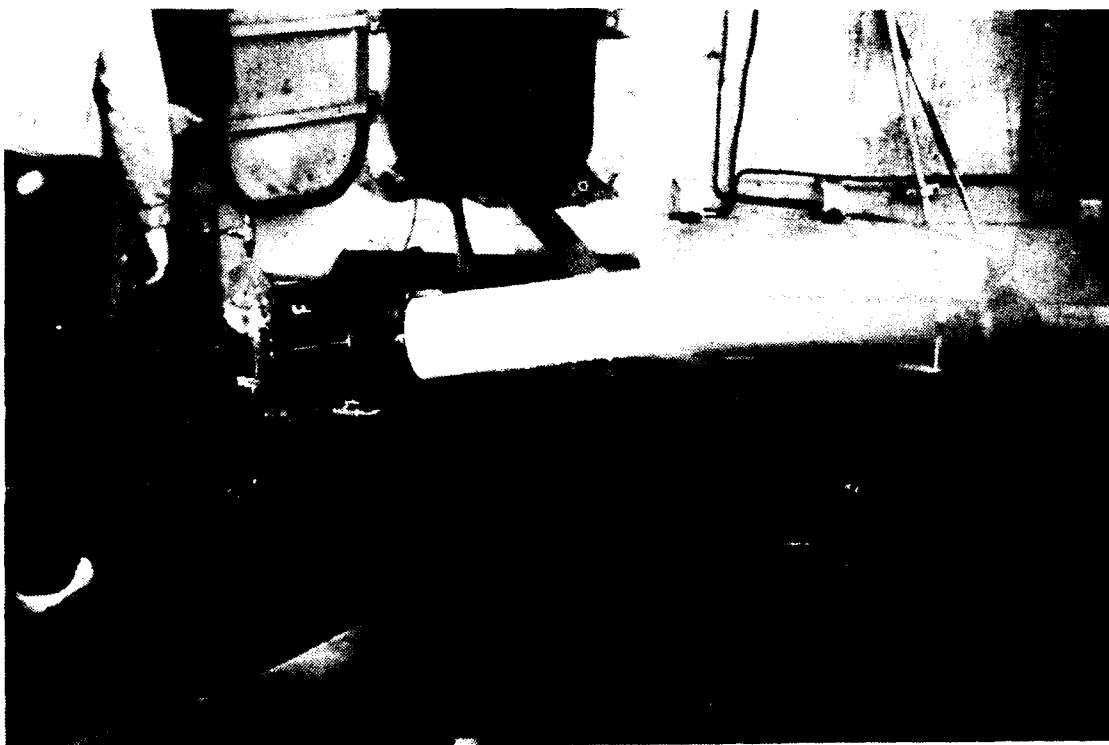


Fig. 7 - RAMFAN with cone adapter



Fig. 8 - Hale Typhoon III equipped with integral spray nozzle



### **5.3 Protective Equipment and Clothing**

Navy personnel wore standard Navy clothing (i.e., khaki pants, shirts, and high-top work boots). Protective equipment included flashhoods (NSN 8414-01-L00-001), DC/fire fighting helmets (NSN 8415-01-271-8069), gloves (NSN 8415-00-F34-5026), and oxygen breathing apparatus (OBA) (NSN 4240-00-F16-2857).

## **6.0 INSTRUMENTATION**

Instruments were installed in the various compartments and along the bulkheads to measure temperature, thermal radiation, smoke density, and gas concentrations. Pressure transducers and ultrasonic flow meters were used to measure the pressure and flow of the inlet and outlet water streams on the water motor fans. A hand held anemometer was used to measure the air velocities of the supply and exhaust ducts. Wind speed and direction were continuously monitored and recorded during each test.

Detailed instrumentation listings, equipment and layouts are shown in Appendix A.

### **6.1 Thermocouples**

Type K, inconel-sheathed thermocouples were used to measure compartment air, overhead and structural element temperatures. These were generally located along the centerline of the wing wall or compartment and located as follows:

1. Vertical strings, five thermocouples per string installed on portable trees, in the following compartments, located 61.0 cm, 91.4 cm, 121.9 cm., 152.4 cm, 182.9 cm (24 in., 36 in., 48 in., 60 in., and 72 in.) above the deck:

- a. Main Deck - CIC, along the centerline of the space at FR 83 and 86 (with an additional thermocouple installed 20.3 cm (8 in.) above the deck).
  - b. Second Deck - RICER 1 (2 strings) and RICER 2 (2 strings); and
  - c. Third Deck - BERTHING 1 (2 strings) and BERTHING 2 (2 strings).
- 2. Vertical strings, two thermocouples per string, located 91.4 cm and 228.6 cm (36 in. and 90 in.) above the deck:
  - a. Second Deck - In the repair locker, access passageway at FR 66, passage (FR 71), (FR 91), and ward room (FR 97); and
  - b. Third Deck - In the engine room escape trunk (FR 66), fan room (FR 70), CPO mess (FR 92), and crew's mess (FR 98).
- 3. Vertical strings, two thermocouples per string, in the overhead of CIC, located 55.9 cm and 121.9 cm (22 in. and 48 in.) above the deck.
- 4. Bulkhead thermocouples, located 91.4 cm and 152.4 cm (36 in. and 60 in.) above the deck, on both sides of bulkheads at the following frames:
  - a. 2nd deck - FR 69, 74, 81, 88, 95, and on the port and starboard hull structures of RICER 2; and
  - b. 3rd deck - FR 67, 74, 81, 88, 95 and on the port and starboard hull structure of BERTHING 2.
- 5. At decks, both sides, on deck structures separating:
  - a. The CIC overhead and CIC,
  - b. CIC and RICER 2,
  - c. RICER 2 and BERTHING 2,
  - d. RICER 1 and BERTHING 1, and
  - e. RICER 2 and the main deck.
- 6. On the steel columns supporting the flight deck, at FR 81 and 88, located 60.0 cm (24 in.) above the deck on the flange facing the well deck and web facing forward.
- 7. For the portable air mover tests, three additional thermocouples were added: one to monitor air temperature at the ventilation hose inlet, one to monitor the temperature directly at the intake of the fan (FR 67) within

the ventilation duct, and one to monitor the temperature at the end of the exhaust duct.

## **6.2 Flux Meters**

Five radiometers (Medtherm Corp. Model 64-5-24 120°) having a range of 0-56.8 kW/m<sup>2</sup> (0-5 Btu/ft<sup>2</sup>s) and one (Medtherm Corp. Model 164P-20-24 120°) ranging from 0-227 kW/m<sup>2</sup> (0-20 Btu/ft<sup>2</sup>s) were used to measure the radiative heat flux. Two calorimeters (Medtherm Corp. Model 64-5-20) having a range of 0-170.1 kW/m<sup>2</sup> (0-15 Btu/ft<sup>2</sup>s), (Medtherm Corp Model 64-15-20), and one ranging from 0-227 kW/m<sup>2</sup> (0-20 Btu/ft<sup>2</sup>s) (Medtherm Corp. Model 64-20-20) were used to measure the total heat flux. All of the heat flux meters were Gardon-type wide angle water cooled devices. These were installed in the following locations:

1. Main deck, in the overhead of CIC viewing the deck;
2. Second deck, in the overhead of RICER 1 and RICER 2, viewing the deck; and the
3. Third deck:
  - a. At FR 90, viewing the bulkhead at FR 88, 182.9 cm (72 in.) above the deck;
  - b. At the wing wall bulkhead at FR 88, viewing BERTHING 2, 61.0 cm (24 in.) and 182.9 cm (72 in.) above the deck (calorimeter only);
  - c. At the bulkhead at FR 74, viewing BERTHING 1, 61.0 cm (24 in.) and 182.9 cm (72 in.) above the deck (calorimeter only);
  - d. On the deck of BERTHING 2, viewing the overhead; and
  - e. In BERTHING 1, FR 79, viewing BERTHING 2 bulkhead, 61.0 cm (24 in.) and 182.9 cm (72 in.) above the deck (radiometers only).

## **6.3 Gas Analyzers**

Gas analyzers were used to continuously monitor the oxygen (Beckman Model 755), carbon monoxide (Beckman Model 865) and carbon dioxide (Beckman Model 865) gas concentrations. The gas sample lines were located in RICER 1 and

BERTHING 1, 152.4 cm (60 in.) and 228.6 cm (90 in.) above the deck, 61.0 cm (24 in.) forward of FR 77 along the port wing wall.

#### **6.4 Pressure and Flow**

Five pressure transducers (Setra Model 207) having a range from 0-7.3 mPa (0-500 psi) were used to measure the water pressure at the following locations:

- the fire plug on the main deck at FR 70,
- the inlet water supply to the RAMFAN on the second deck at FR 68,
- the outlet water from the RAMFAN on the second deck at FR 68,
- the inboard overboard discharge on the second deck at FR 68, and
- the inlet water supply to the Hale Typhoon blower on the third deck FR 88.

In addition, an ultrasonic flowmeter (Controlotron 9000 series) was used to monitor the flow to the water motor fan from FPL 1-70-2.

#### **6.5 Smoke Density**

Smoke obscuration was measured using five infrared light emitting diode (IRLED) smoke meters (TSI Inc.) [8]. Two meters were located in RICER 1 along the outboard bulkhead between FR 77 and 76 at 152.4 cm (60 in.) and 245 cm (96 in.) above the deck. In BERTHING 1, two smoke meters were located at the same locations as in RICER 1, with an additional smoke meter above the lintel of WTD 3-81-2 at FR 81, 186.7 cm (73 in.) above the deck (Figs. 9-11).

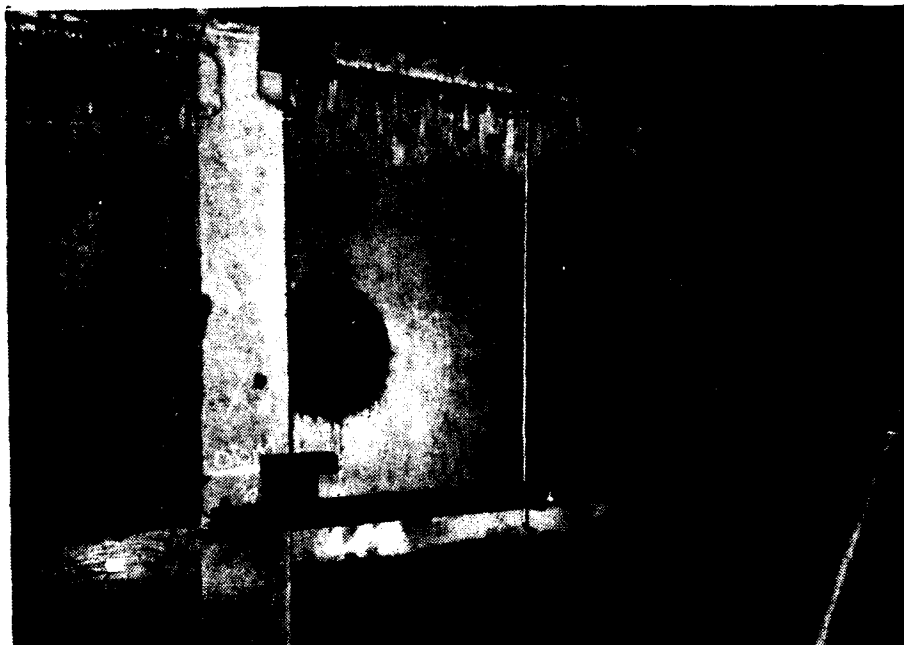
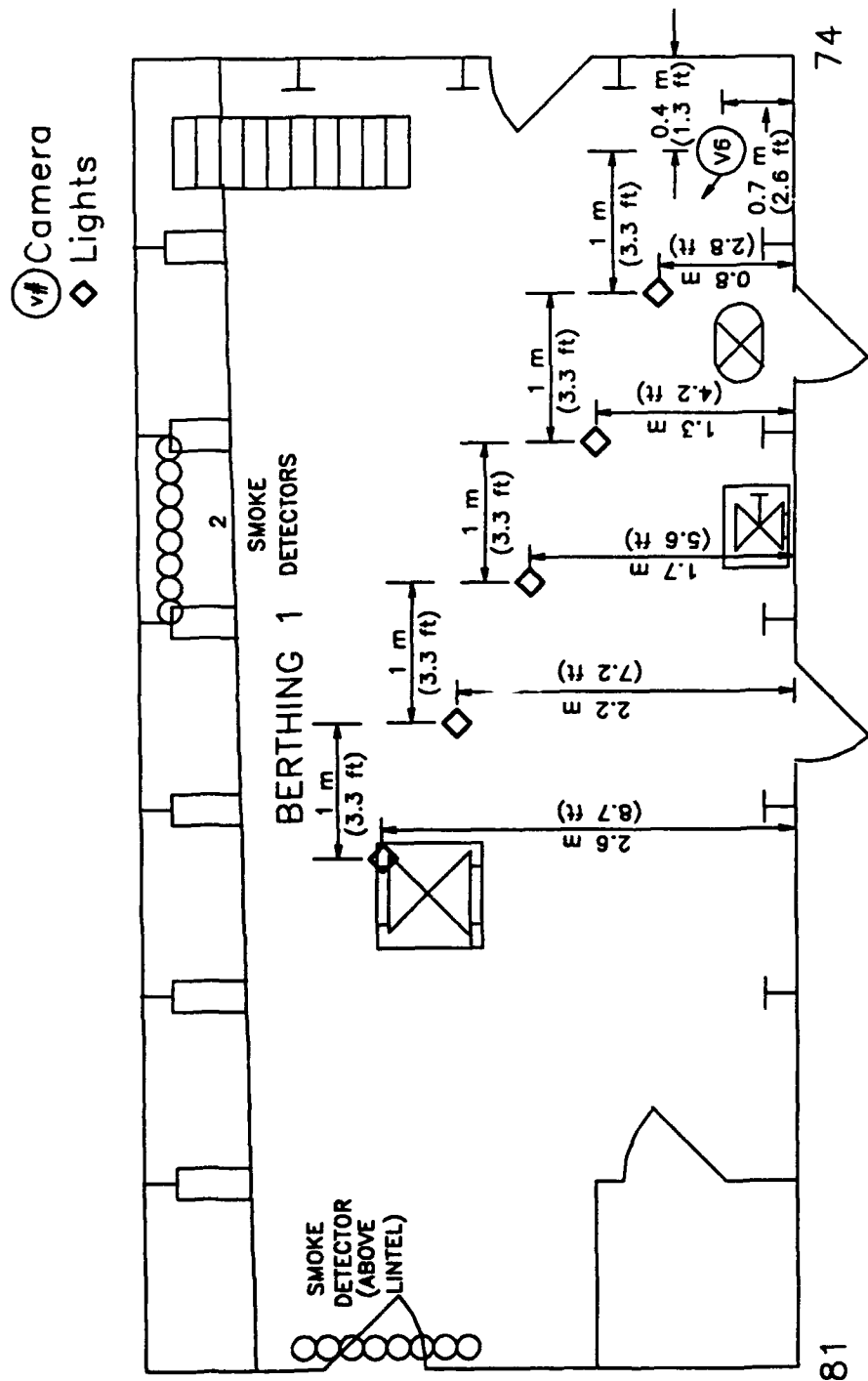


Fig. 9 - Optical density meters and gas ports in RICER 1

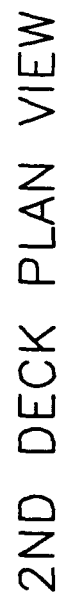


# 3RD DECK PLAN VIEW

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BH 74-81

Fig.10- Location of light stringer and smoke detectors in BERTHING 1



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BH 74-81

**Fig.1 1- Location of light stringer and smoke detectors in RICER 1**

## **6.6 Hydrocarbon Alarm**

For safety reasons, a hydrocarbon gas analyzer (MSA Model 5000) was used to monitor the concentration of hydrocarbon gas. The gas sampling device was installed in RICER 1. The audible alarm, located in the control room, was set to sound when the concentration of the hydrocarbons exceeded 20% of the lower flammability limit.

## **6.7 Air Velocity**

A hand-held anemometer (Hastings Model AB27) was used to measure the velocity of the supply and exhaust from the blowers. These measurements were taken prior to actual fire testing of the blowers.

## **6.8 Visibility Measurements**

A string of five 25 watt incandescent light bulbs were installed in BERTHING 1 and RICER 1 as shown in Figs. 10 and 11. The bulbs were located 1 m (3.3 ft) from the camera and 1 m (3.3 ft) apart from each other. These bulbs were used to track the smoke as it moved through the compartments [9,10].

## **6.9 Visual and Audio Recordings**

Visual and audio recordings were made for all tests. The following is a list of video (V) and audio (A) locations:

- V1,A1.        RICER 1 viewing forward
- V2.            Starboard wing wall viewing fire area
- V3.            Second deck FR 68 viewing aft



- V4. RICER 1 viewing light string
- V5. PRY FLY viewing FR 74 - FR 81 of the port wing wall
- V6. BERTHING 1 viewing light string
- V7,A2. Main deck of port wing wall viewing aft or forward depending on test
- V8,A3. Second deck FR 73 viewing forward or third deck at FR 90 viewing BERTHING 2 depending on test.

In addition, a portable video camera was used to record the debriefings of the manned tests and the supplementary lift test. Still photographs were used to document fan equipment and pre- and post-fire test conditions.

#### **6.10 Communication System**

A public address announcing system (1MC) and two way radios were available for each fire test. The 1MC system was used to clear the test area prior to ignition and to call away the fire. Two way communications were maintained between the control room and the test personnel throughout each test.

### **7.0 TEST SCENARIOS AND PRELIMINARY TESTS**

Testing was conducted on the port wing wall between FR 60-95 (Fig. 1). BERTHING 2 served as the burn area while the desmoking effectiveness was measured in BERTHING 1 and RICER 1. For the unmanned experiments, two different desmoking conditions were evaluated:

- Static smoke/heat conditions, that is, after the fire was extinguished, as is recommended under current fire fighting doctrine, and
- Dynamic smoke/heat conditions where the fire was still burning when desmoking was initiated.

For the manned experiments, desmoking was initiated only after the fire was extinguished.

## 7.1 Test Variables

The principle variables were related to the capacity of the blowers and the ease of handling. The specific blower combinations were as follows:

- Red Devil with 20.3 cm (8 in.) ventilation ducting,
- Red Devil with 25.4 cm (10 in.) ventilation ducting,
- RAMFAN at low inlet water pressure (nominally 345 kPa (50 psi)), and
- RAMFAN at high inlet pressure (nominally 965 kPa (140 psi)).

Manned intervention was a factor because it determined the ease of handling of the fans. This was quantitatively determined by the measured setup times and qualitatively assessed during post-test debriefings.

An additional variable was the method of make-up air. Mechanical desmoking is dependent on the amount of make-up air available to the smoke-filled area. Without fresh make-up air, mechanical extraction of smoke is highly inefficient [11]. Two conditions were evaluated with the blowers operating:

- fresh make-up air supplied near the exhaust locations, and

- fresh make-up air supplied at a location remote from the exhaust location.

To establish a baseline for comparison, several tests were conducted during the background fire tests with no fresh make-up air supplied to the fire/smoke area.

## **7.2 Water Motor Fan Performance Prior to Fire Testing**

Prior to the fire tests, the performance of the water motor fans were evaluated. Eleven preliminary performance tests were conducted with the RAMFAN and the fan that supplied combustion air to the fire compartment, the Typhoon fan. The optimum supplies to the fans were determined given the capacity of the fire pump. The operating supply pressures for the fans were determined for the fire tests which were approximately 220 kPa (32 psi) for the Typhoon fan and 345 kPa (50 psi) and 965 kPa (140 psi) for the RAMFAN at "low" and "high" pressures, respectively. The air flows were determined for the RAMFAN using 1 section of suction duct on the inlet and 2 sections of discharge duct on the outlet, both 25.4 cm (10 in.) in diameter. The hoses for the water supply and discharge were 3.81 cm (1.5 in.). Both hoses and ducts were rigged in the same manner as in the fire tests. Table 1 lists the water supplies to the fans and the air flow rates for the RAMFAN and Typhoon fan. Air flow measurements were also taken on the RAMFAN with the water mister attachment, and the cone attachment. These results are given in Table 7 of Section 10.

## **7.3 Background Fire Tests**

Table 2 is a list of the background fire tests that were performed to establish the "static" and "dynamic" design fires in this test series. Fire tests were given the name of FAN\_#. Ten background fire tests were conducted to find the appropriate design fire size to test the blowers. All of these tests were conducted with the unmanned, static condition setup using the Red Devil Blower with the 20.3 cm (8 in.) duct as described in Sections 8.1 and 8.2. The standard fire selected from the background fire tests was a 15.14  $\ell$  (4.0 gal) heptane fire which produced the desired

Table 1. Prefire Flow Tests (10/16/90)

Pump Freq.	Fire Main Pres.	Hydt. Pres.	Typhoon Flow	Typhoon Pres.	RAMFAN Inlet Pres.	RAMFAN Outlet Pres.	RAMFAN Flow	OVBD Dischg. Pres.	RAMFAN Suction Duct Flow	RAMFAN Dischg. Duct Flow
FAN_1-Typhoon and RAM on										
40Hz	496 kPa (72 psi)	324 kPa (47 psi)	420 fpm (111 gpm)	234 kPa (34 psi)	345 kPa (50 psi)	69 kPa (10 psi)	129 fpm (34 gpm)	14 kPa (2 psi)	6.9 cmm (245 cfm)	2.8 cmm (98 cfm)
FAN_2-Typhoon on and RAM off										
40Hz	496 kPa (72 psi)	NR	424 fpm (112 gpm)	220 kPa (32 psi)	-	-	-	-	-	-
FAN_3-Typhoon on and RAM off										
40Hz	565 kPa (82 psi)	NR	390 fpm (103 gpm)	NR	-	-	-	-	-	-
FAN_4-Typhoon and RAM on										
50Hz	868 kPa (126 psi)	840 kPa (122 psi)	556 fpm (147 gpm)	372 kPa (54 psi)	827 kPa (120 psi)	103 kPa (15 psi)	242 fpm (64 gpm)	41 kPa (6 psi)	6.9 cmm (245 cfm)	6.2 cmm (220 cfm)
FAN_5-Typhoon on and RAM off										
50Hz	868 kPa (126 psi)	NR	556 fpm (147 gpm)	379 kPa (55 psi)	-	-	-	-	-	-
FAN_6-Typhoon off and RAM on										
50Hz	854 kPa (124 psi)	827 kPa (120 psi)	-	-	841 kPa (122 psi)	103 kPa (15 psi)	257 fpm (68 gpm)	41 kPa (6 psi)	NR	NR

NR = not recorded

Table 1. Prefire Flow Tests (10/16/90) (Continued)

Pump Freq.	Fire Main Pres.	Hydt. Pres.	Typhoon Flow	Typhoon Pres.	RAMFAN Inlet Pres.	RAMFAN Outlet Pres.	RAMFAN Flow	OVBD Dischg. Pres.	RAMFAN Suction Duct Flow	RAMFAN Dischg. Duct Flow
FAN_7-Typhoon and RAM on										
57Hz	1006 kPa (146 psi)	999 kPa (145 psi)	424 lpm (112 gpm)	220 kPa (32 psi)	978 kPa (142 psi)	103 kPa (15 psi)	265 lpm (70 gpm)	41 kPa (6 psi)	8.6 cmm (304 cfm)	6.9 cmm (245 cfm)
FAN_8-Typhoon off and RAM on										
57Hz	1006 kPa (146 psi)	999 kPa (145 psi)	-	-	978 kPa (142 psi)	103 kPa (15 psi)	273 lpm (72 gpm)	41 kPa (6 psi)	8.6 cmm (304 cfm)	6.9 cmm (245 cfm)
FAN_9-Typhoon and RAM on										
57Hz	1006 kPa (146 psi)	NR	329 lpm (87 gpm)	179 kPa (26 psi)	930 kPa (135 psi)	90 kPa (13 psi)	NR	NR	NR	NR
FAN_10-Typhoon and RAM on										
57Hz	951 kPa (138 psi)	NR	640 lpm (169 gpm)	648 kPa (94 psi)	909 kPa (132 psi)	83 kPa (12 psi)	269 lpm (71 gpm)	NR	NR	NR
FAN_11-Typhoon off and RAM on										
40Hz	558 kPa (81 psi)	324 kPa (47 psi)	-	-	345 kPa (50 psi)	55 kPa (8 psi)	144 kPa (38 gpm)	14 kPa (2 psi)	2.8 cmm (98 cfm)	2.1 cmm (73 cfm)

NR = not recorded

Table 2. Background Fire Tests

<u>Test</u>	<u>Fuel Load</u>
SAM FAN	11 ℓ (3 gal), then 7.5 ℓ (2 gal) heptane
FAN_1	11 ℓ (3 gal) heptane
FAN_2	11 ℓ (3 gal) heptane
FAN_3	15 ℓ (4 gal) heptane
FAN_4	11 ℓ (3 gal) heptane and 3.8 ℓ (1 gal) diesel
FAN_5	11 ℓ (3 gal) heptane and 1 ℓ (1 qt) diesel
FAN_6	11 ℓ (3 gal) heptane and 1 ℓ (1 qt) diesel
FAN_7	11 ℓ (3 gal) heptane
FAN_8	11 ℓ (3 gal) heptane
FAN_9	11 ℓ (3 gal) heptane
FAN_10	15 ℓ (4 gal) heptane

smoke and heat characteristics in the adjacent and remote spaces. Inlet combustion air was based on an inlet water flow to the Typhoon of 420  $\ell$ pm (111 gpm). The data for the complete test series, i.e. smoke information, temperatures, gas generation/depletion, are located in Appendix B.

## 8.0 STATIC FIRE TESTS

Baseline fire tests were conducted using the Red Devil 20.3 cm (8 in.) and 25.4 cm (10 in.) ducts. These tests provided a basis for comparison for the RAMFAN. During these static tests, a 15  $\ell$  (4 gal) heptane pool fire was used to compare the fans. Variables for these tests were the type of fan, fan pressure, location of the make-up air, and manned vs. unmanned. The fire tests with the RAMFAN were essentially conducted in two different scenarios—high pressures and low pressures. High pressure tests were conducted with a water inlet pressure of approximately 965 kPa (140 psi) at the fan and low pressure tests had an inlet pressure of approximately 345 kPa (50 psi) at the fan. Make-up air was supplied at either WTD 3-88-2 or at WTD 2-74-2. Table 3 is a list of the static fire tests performed.

### 8.1 Setup

Figure 12 shows the setup of the static fire tests prior to desmoking. Smoke curtains were hung at WTD 3-88-2 and 2-74-2. Combustion air to the fire compartment (BERTHING 2) was supplied via a 0.09 m<sup>2</sup> (1 ft<sup>2</sup>) opening in the smoke curtain. The door at 3-81-2 and the scuttle at 2-74-2 were left open to allow the smoke to move from BERTHING 2 to BERTHING 1 and RICER 1. Otherwise, all other openings were sealed.

Table 3. Static Fire Tests

<u>Test</u>	<u>Fan/Duct</u>	<u>Inlet Pressure</u>	<u>Manned/ Unmanned</u>
FAN_11	Red Devil 25.4 cm (10 in.)	--	U
FAN_12	Red Devil 25.4 cm (10 in.)	--	U
FAN_13	RAMFAN*	965 kPa (140 psi)	U
FAN_15	RAMFAN	345 kPa (50 psi)	U
FAN_16	Red Devil 25.4 cm (10 in.)	--	M
FAN_17	Red Devil 20.3 cm (8 in.)	--	M
FAN_18	RAMFAN	930-965 kPa (135-140 psi)	M
FAN_19	Red Devil 25.4 cm (10 in.)	--	M
FAN_20	RAMFAN	345 kPa (50 psi)	M
FAN_21	RAMFAN	345 kPa (50 psi)	M
FAN_22	RAMFAN	1000 kPa (145 psi)	M
FAN_23	RAMFAN	1000 kPa (145 psi)	M
FAN_37	RAMFAN	345 kPa (50 psi)	U
FAN_38	RAMFAN	345 kPa (50 psi)	U
FAN_39	--	--	U
FAN_40	--	--	U

\* All duct used with RAMFAN was 25.4 cm (10 in.).





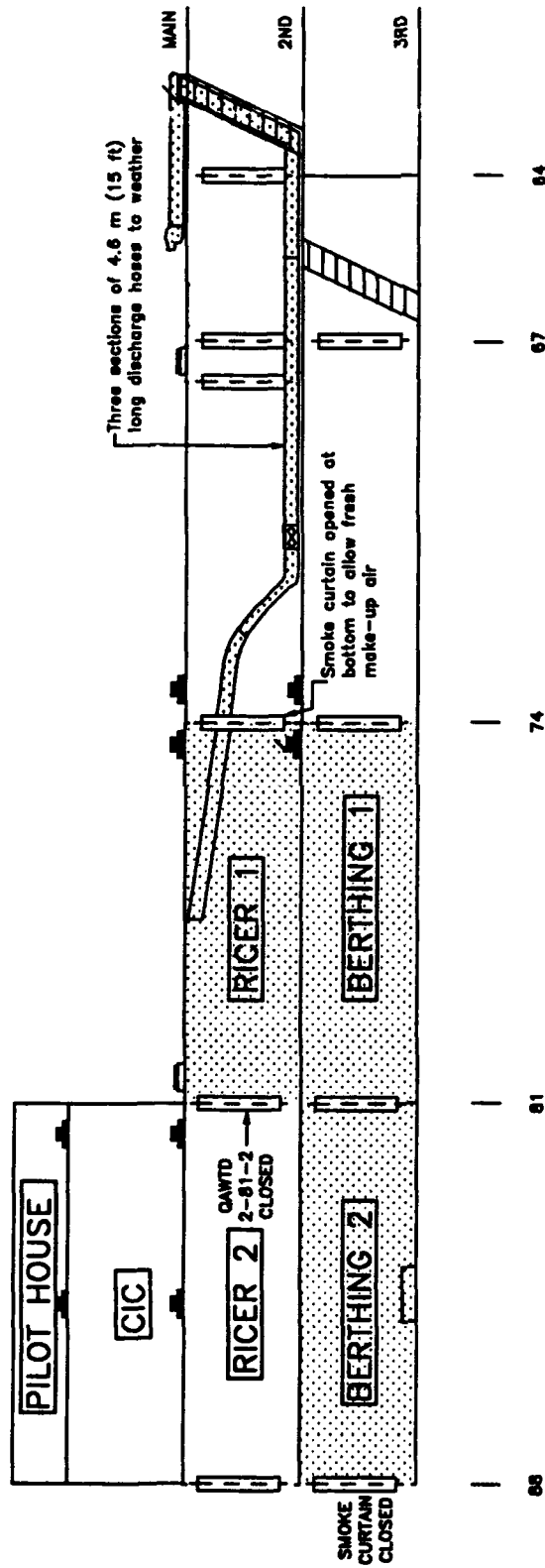
Two 4.6 m (15 ft) sections of ventilation duct were pre-hung from the center of RICER 2 overhead, extending through the smoke curtain at WTD 2-74-2. In the unmanned tests, the blower was prerigged and the ventilation ducts were in place as shown in Fig. 13. AC power was supplied to the Red Devil blowers from a repair locker at 2-68-2. For the RAMFAN, 30.5 m (100 ft) of 1½ in. hose connected to FPL 1-70-2 was used to supply the fan. It was routed through the same compartments as the exhaust duct. The pressure to the RAMFAN was controlled at FPL 1-70-2. The outlet hose from the RAMFAN was connected to an overboard discharge at 2-68-2, inboard side of the portwing wall, which discharged to the well on the third deck.

In the manned tests, two members of the desmoking team and a test team observer were staged in Repair 4, temporary located for this test series at 1-58-2. When they were called away to desmoke the compartments, they installed the equipment as shown in Fig. 14. Power to the Red Devil and water to the RAMFAN was supplied in the same manner as in the unmanned tests.

## 8.2 Procedures

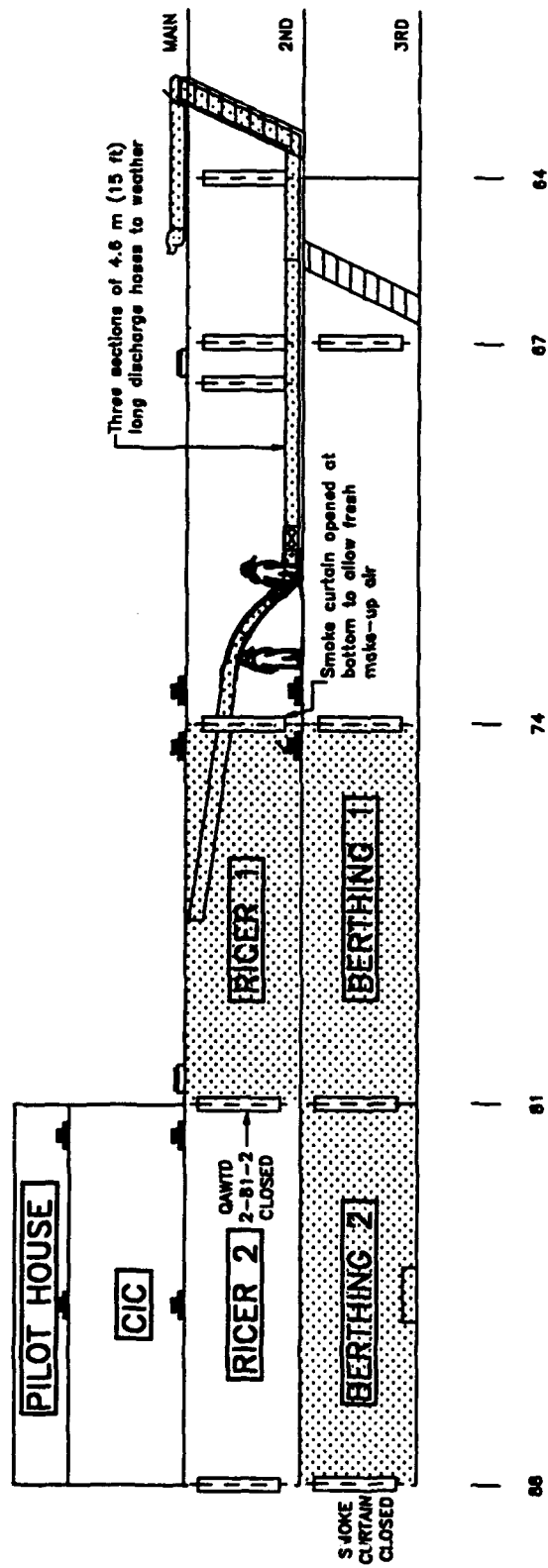
Prior to each test, the fire area was cleared of all personnel. The designated safety officer during these tests patrolled the aft section of the ship. Two persons were positioned at the well deck to pour and ignite the 15.14 ℓ (4.0 gal) of heptane and to keep watch on the fire while it burned.

When the test director gave the command, the fuel was poured into the middle pan of BERTHING 2 and ignited. The heptane fire burned approximately 4.5-5 minutes. The smoke curtain at 3-88-2 was cracked open to provide combustion air until the fire burned out. The smoke curtain at WTD 3-88-2 was then sealed. The following specific procedures were used in the Unmanned and Manned series:



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Fig. 13 - Section view, static test, unmanned desmoking



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Fig. 14 - Section view, static test, manned desmoking

### 8.2.1 Unmanned

For the unmanned tests, the desmoking fan was activated 15 minutes after ignition in Bertning 2. Make-up air was provided via openings in the smoke curtain at WTD 3-88-2 or 2-74-2 by a test team member.

### 8.2.2 Manned

Prior to ignition, two members of the desmoking team were staged in Repair 4. They were dressed in normal work clothing. For safety, they wore OBAs, flashhoods, and fire fighters helmets. Dressed in this equipment, the desmoking team activated their OBA's prior to ignition of the fire. At the time of ignition, they were called away to desmoke the compartments. The desmoking team proceeded to the second deck via the hatch at 1-62-2 and installed the equipment as shown in Fig. 14. They either connected the water supply hose to the RAMFAN or plugged the Red Devil to the receptacle in the repair locker. The exhaust ducts were installed, the static ground line connected, and the water discharge hose connected to an overboard discharge at 2-70-2 for the RAMFAN. When all the equipment was ready, the blower was activated by opening the valve at FPL 1-70-2. During the static tests, the heptane fire was burned out prior to initiation of desmoking. After the fan was in service, make-up air was supplied to the smoke-filled area at either QAWTD 2-74-2 below the ventilation hose or QAWTD 3-88-2. The opening at 3-88-2 was approximately  $0.09 \text{ m}^2$  ( $1 \text{ ft}^2$ ).

## 8.3 Results

The performance of the blowers was evaluated quantitatively by comparing thermal, fire gas, and smoke obscuration recovery rates. To qualitatively evaluate the density of the smoke, incandescent lights were used to track the movement of the smoke. The ability to see the lights offered a correlation between the smoke detectors and visibility in a smoke filled environment.

For FAN\_10 through FAN\_23, a 15.12 l (4 gal) heptane fire was used to evaluate the blower's performance. FAN\_10 through FAN\_16 were unmanned fire tests while FAN\_17 through FAN\_23 were manned. FAN\_10, 12, 15, and 16 of the unmanned tests were selected for evaluation because the same variables were used, i.e., same location for make-up air. FAN\_11 was conducted to evaluate the different location of the make-up air and will be discussed in Section 8.3.5. FAN\_13 was not evaluated because the smoke curtain at 3-88-2 was inadvertently left opened during the soak period. FAN\_14 was not evaluated because strong ambient wind conditions appear to have affected the smoke production. There were wind gusts up to 375.54 m/min (14 mph). For the manned tests, FAN\_17, 18, 19, 20, and 22 were used to evaluate the performance of the blowers and will be discussed in this section. FAN\_21 and 23 were conducted to evaluate the location of the make-up air.

### 8.3.1 Smoke Obscuration

Figures 15 through 32 show the percent transmittance as a function of time for the representative tests in BERTHING 1 and RICER 1. These figures include background time, i.e. the time before ignition is shown. Since the smoke concentration at the time of desmoking varied for each test, the percent recovery of smoke for the tests were compared. This allows a direct comparison of tests. Equation 1 was used to attain the normalized transmittance:

$$\Gamma = \frac{T_n - T_i}{T_f - T_i} \times 100 \quad (1)$$

where

- $\Gamma$  = normalized transmittance,
- $T$  = transmittance,
- $i$  = initial number,
- $f$  = final number, and
- $n$  = nth number.

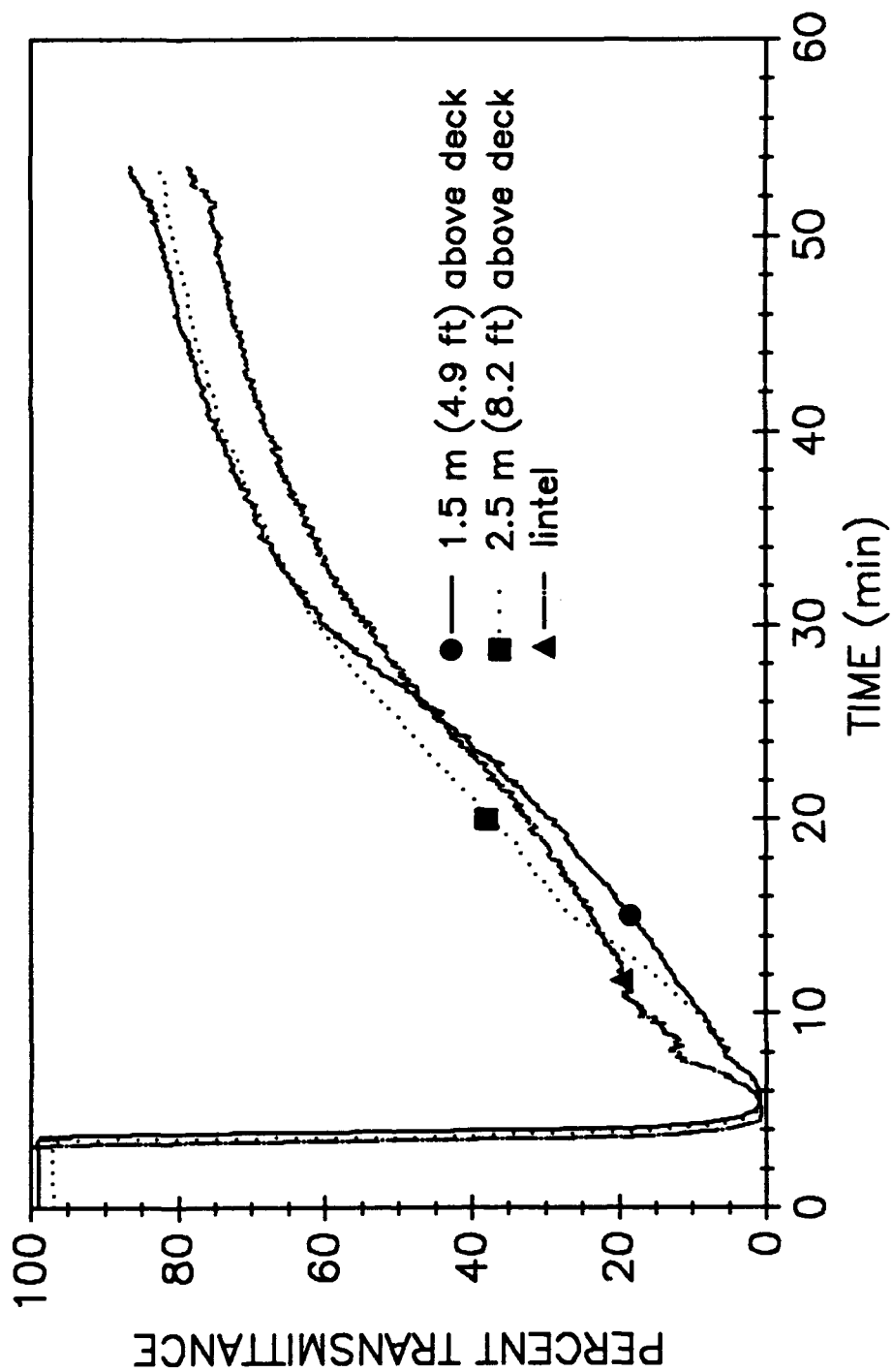


Fig. 15 - Percent transmittance in BERTHING 1 during FAN\_10  
using Red Devil 20.3 cm (8 in) duct

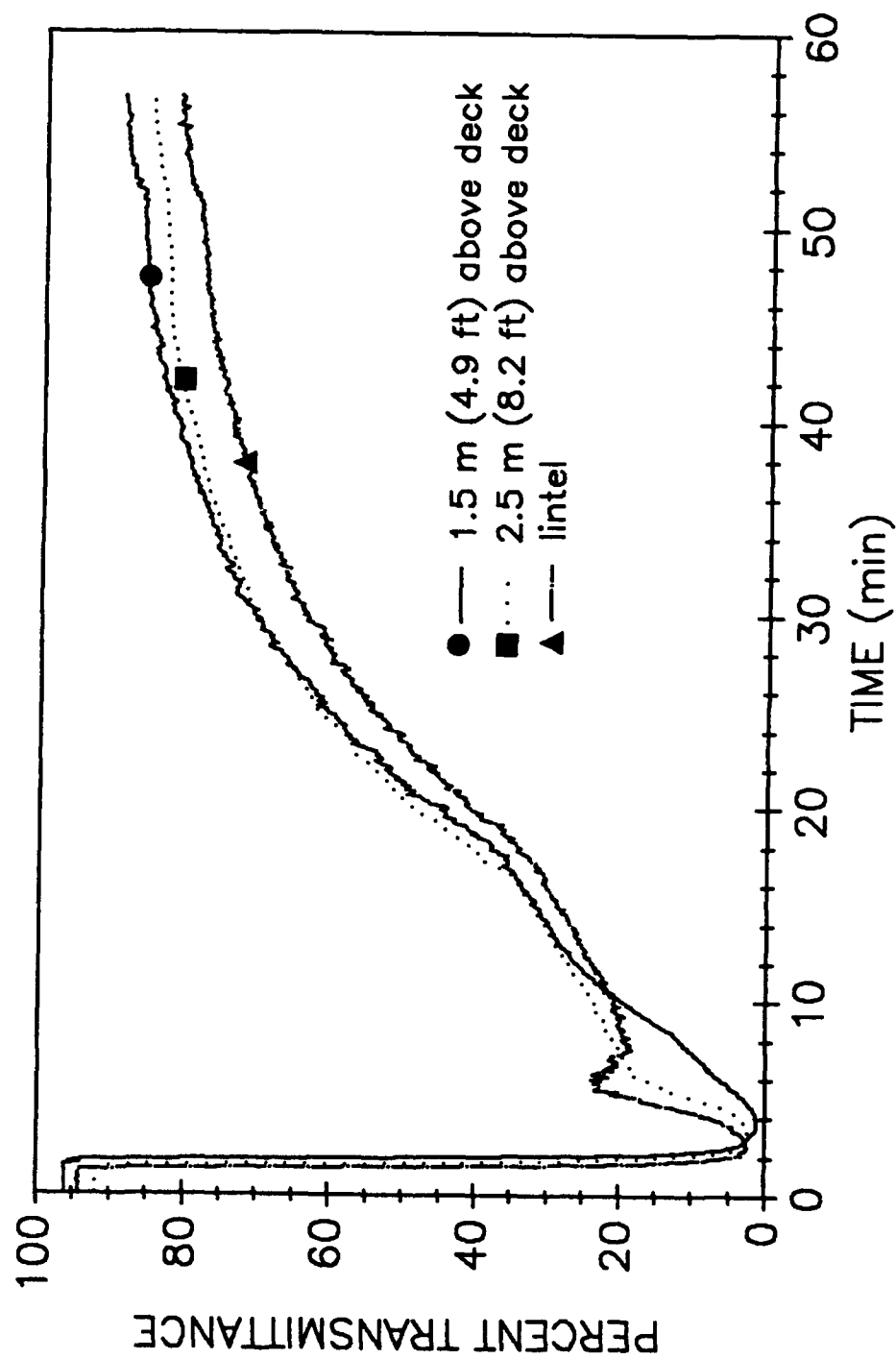


Fig. 16 - Percent transmittance in BERTHING 1 during FAN\_12  
using Red Devil 25.4 cm (10 in) duct



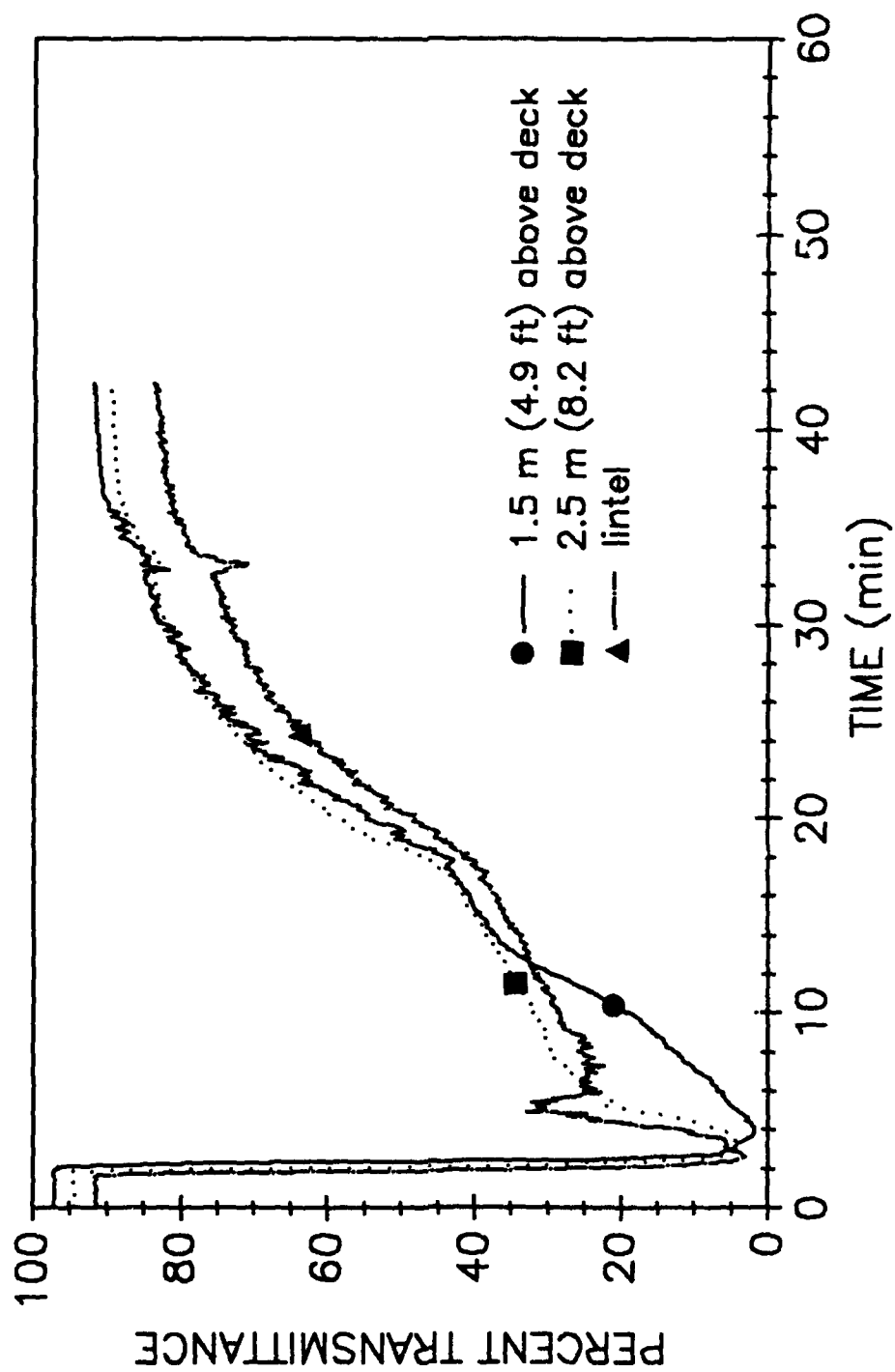


Fig. 17 - Percent transmittance in BERTHING 1 during FAN\_15  
RAMFAN 345 kPa (50 psi)

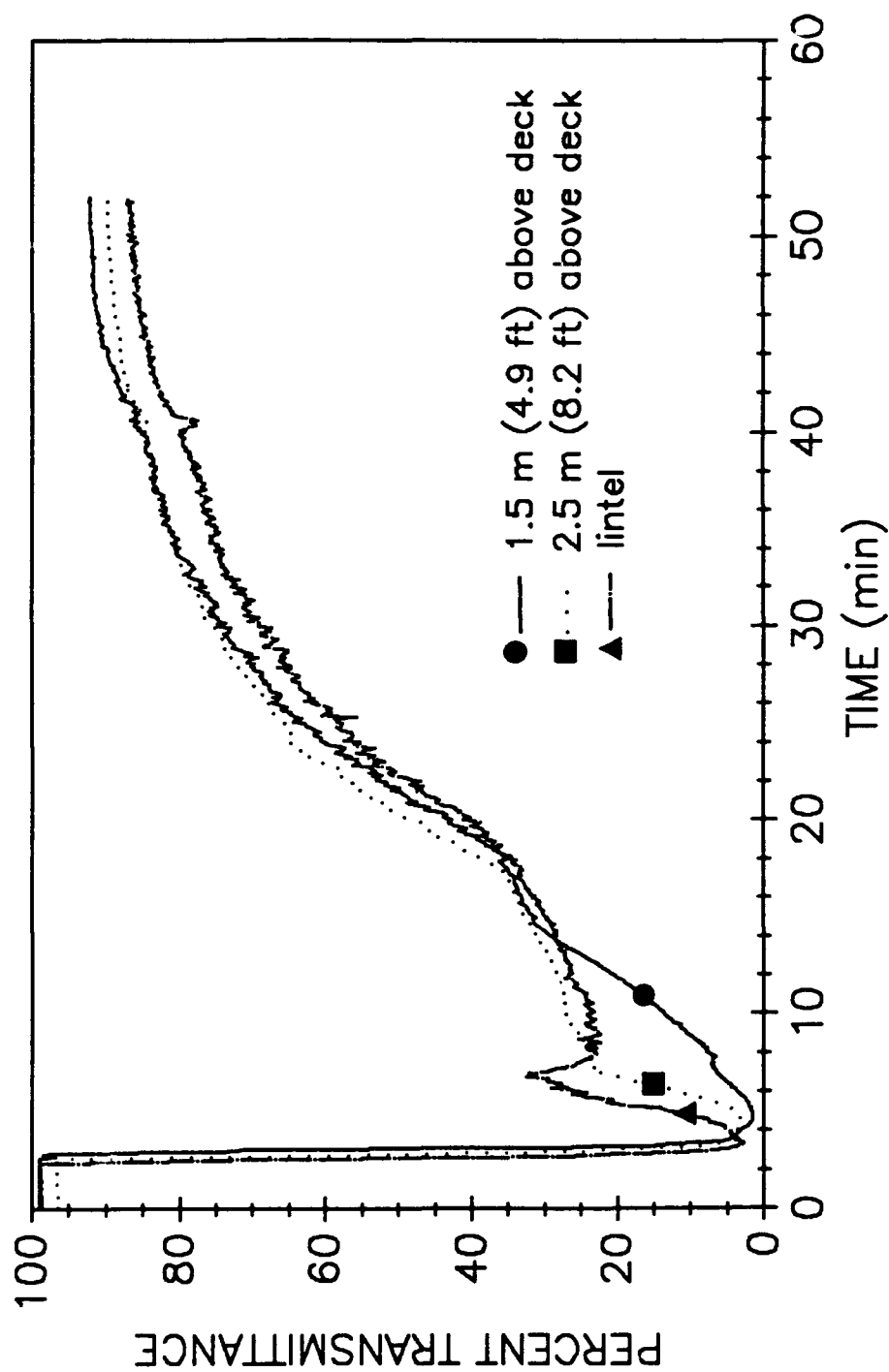


Fig. 18 - Percent transmittance in BERTHING 1 during FAN\_16  
using Red Devil 25.4 cm (10 in) duct

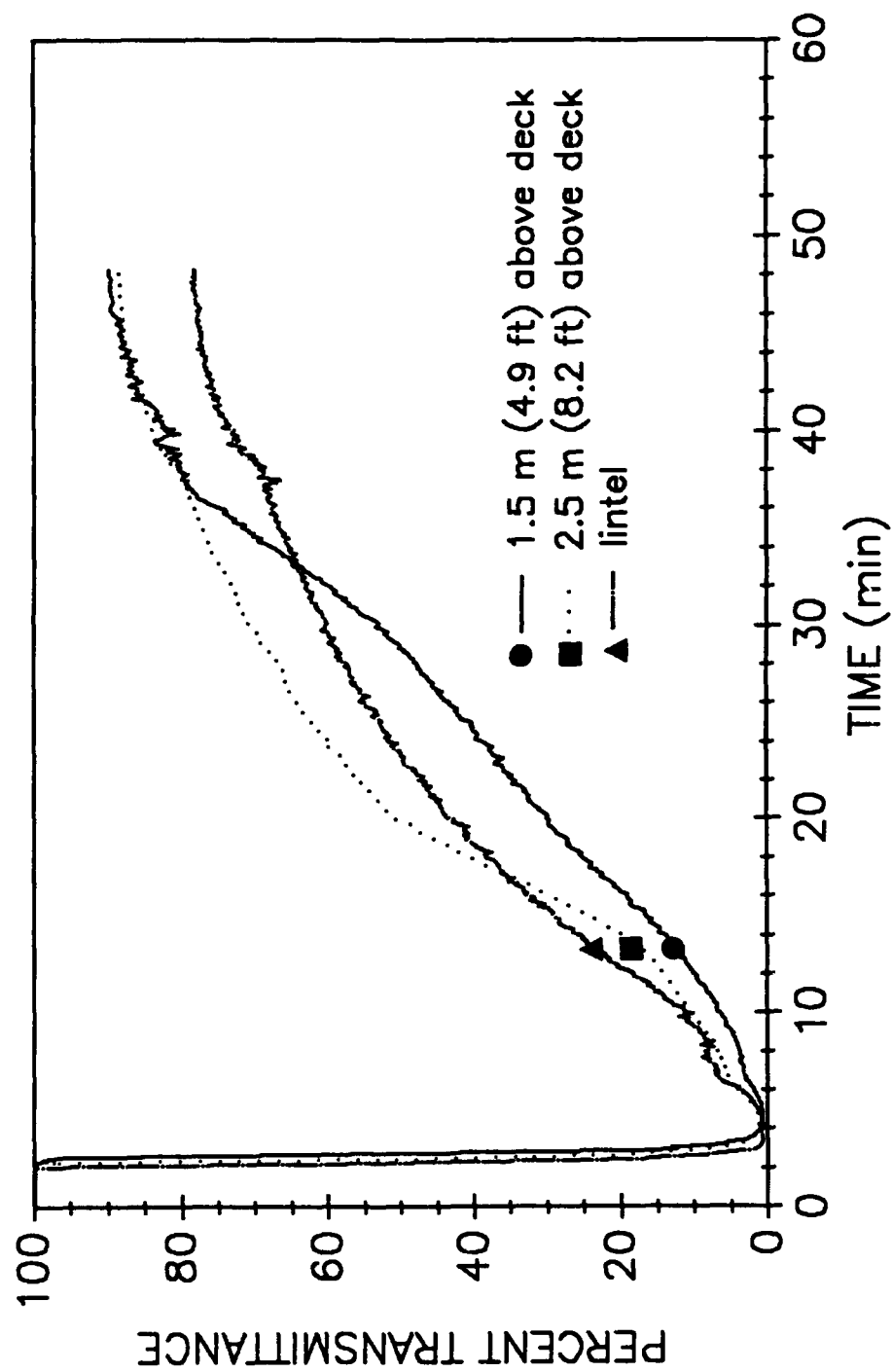


Fig. 19 - Percent transmittance in BERTHING 1 during FAN\_17  
using Red Devil 20.3 cm (8 in) duct

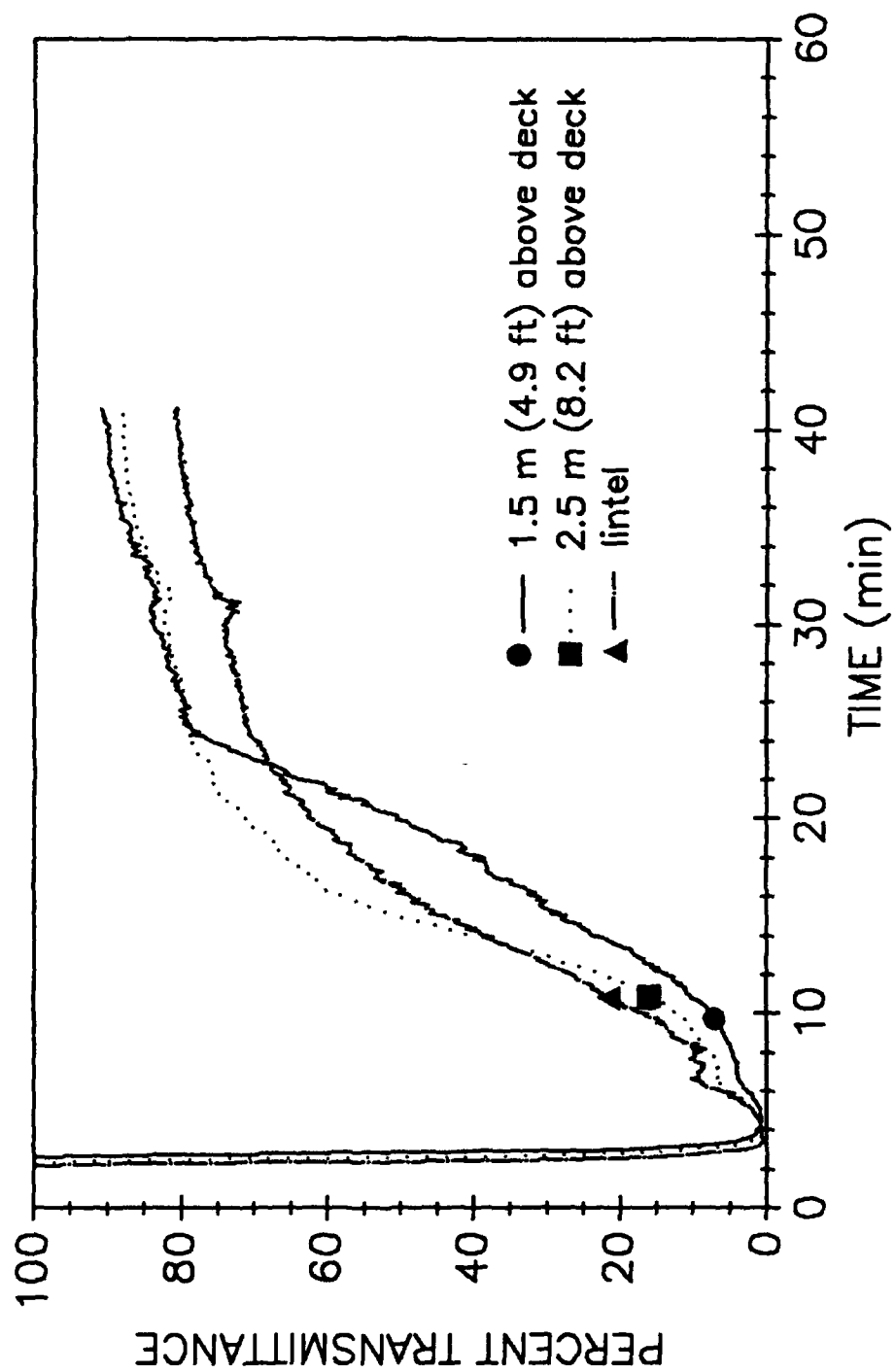


Fig. 20 - Percent transmittance in BERTHING 1 during FAN\_18  
using RAMFAN 956 kPa (140 psi)

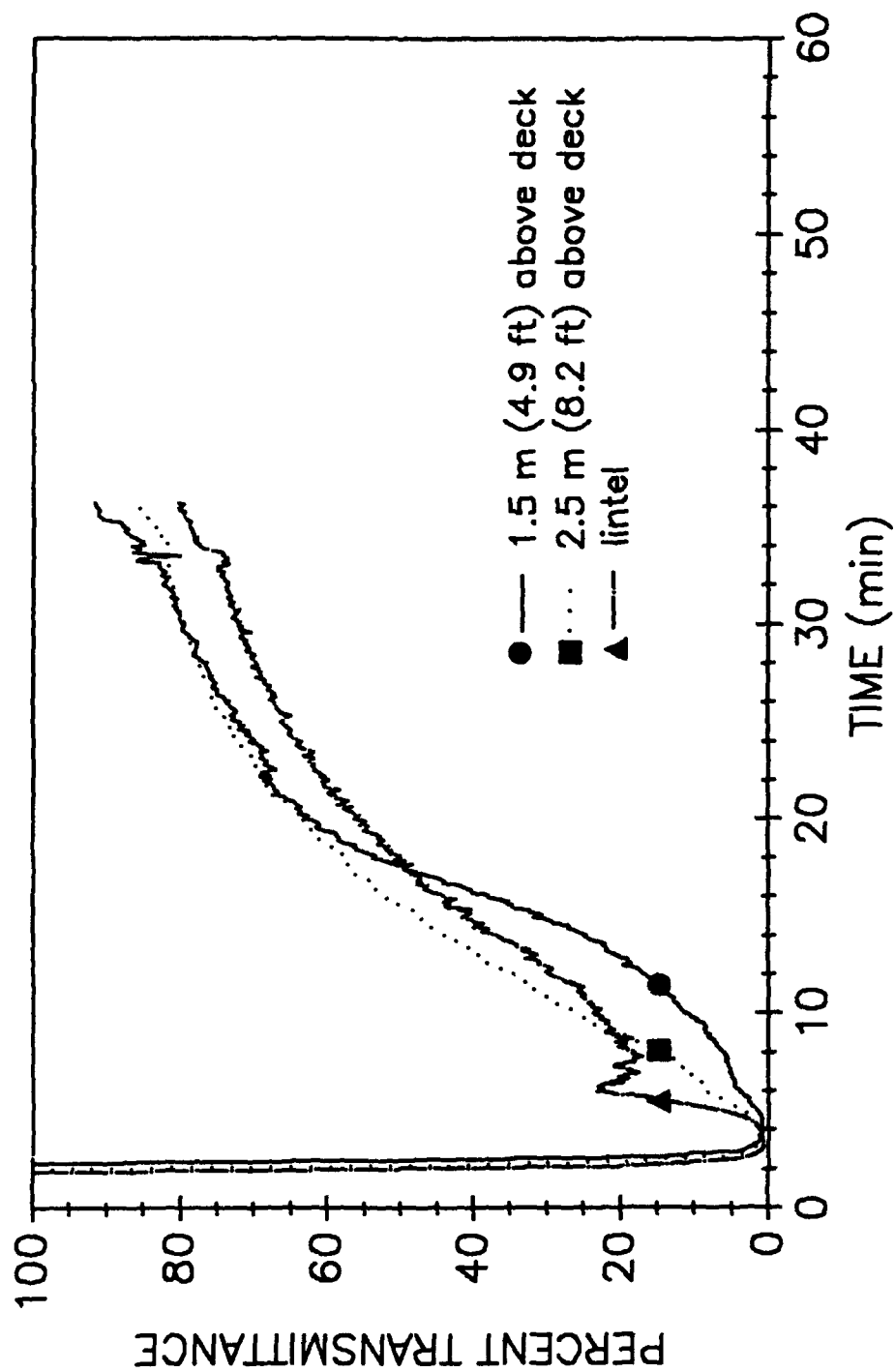


Fig. 21 - Percent transmittance in BERTHING 1 during FAN\_19  
using Red Devil 25.4 cm (10 in) duct

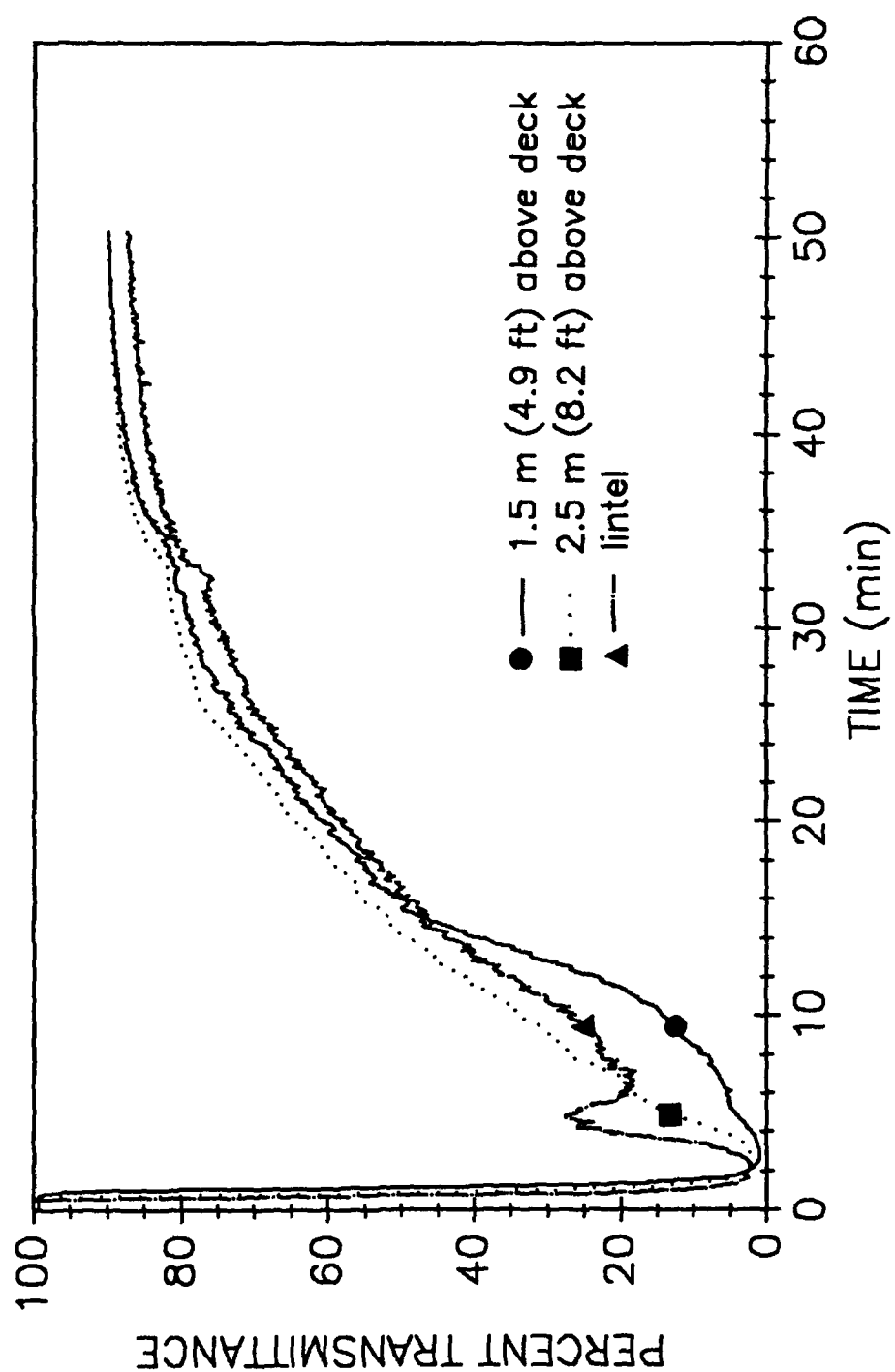


Fig. 22 - Percent transmittance in BERTHING 1 during FAN\_20  
using RAMFAN 345 kPa (50 psi)

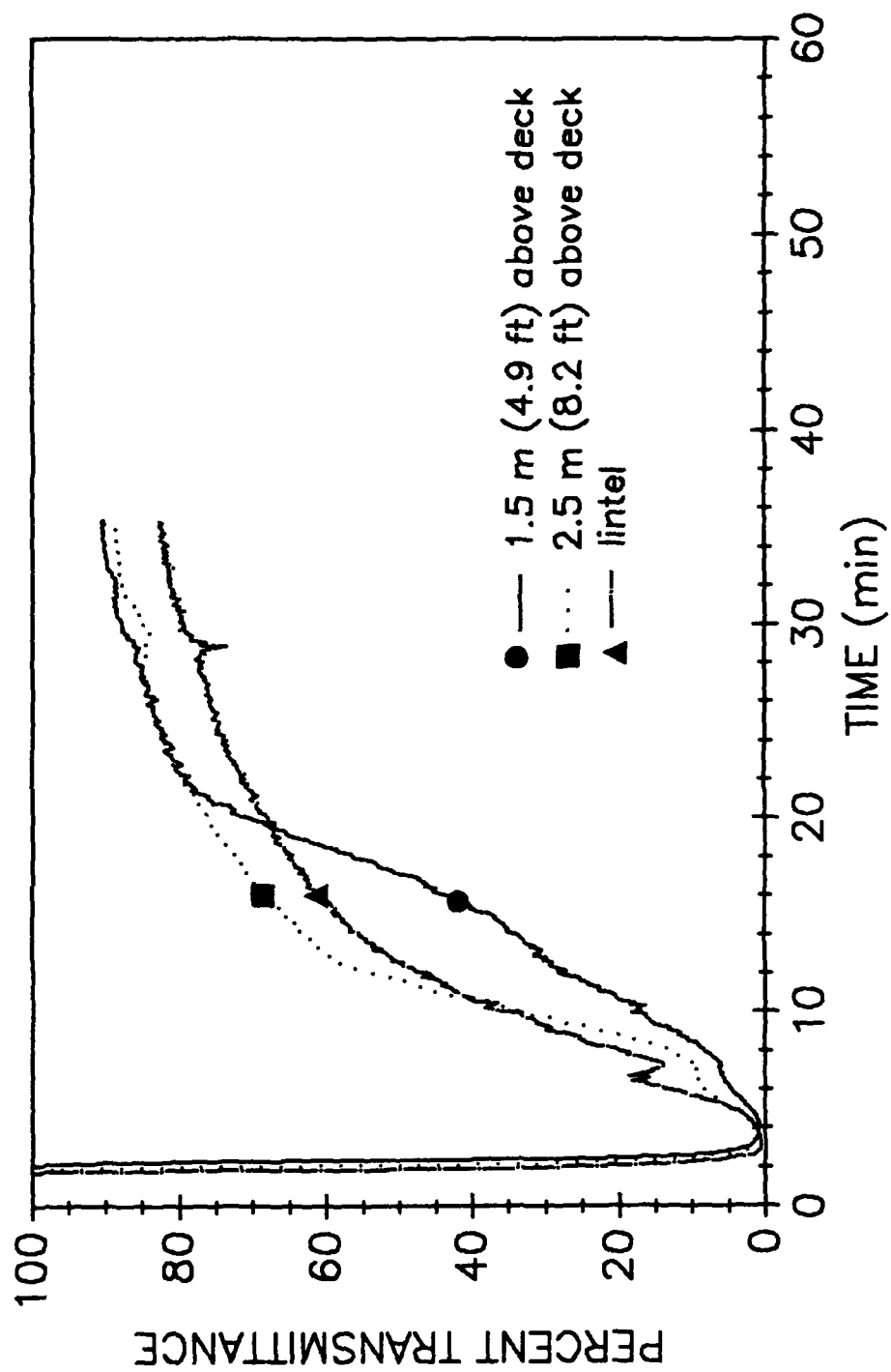


Fig. 23 - Percent transmittance in BERTHING 1 during FAN\_22 using RAMFAN 1000 kPa (145 psi)

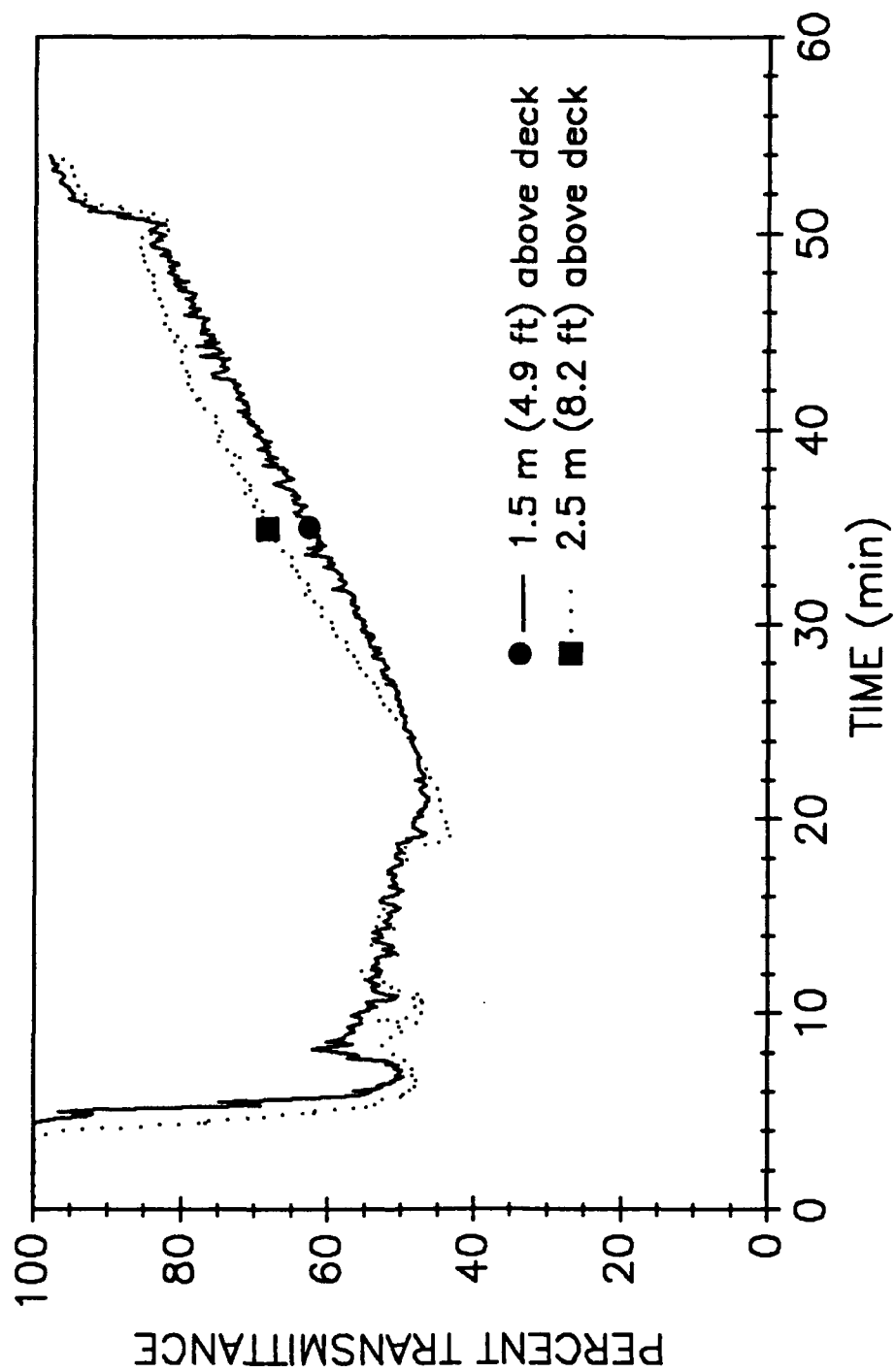


Fig. 24 - Percent transmittance in RICER 1 during FAN\_10  
using Red Devil 20.3 cm (8 in) duct



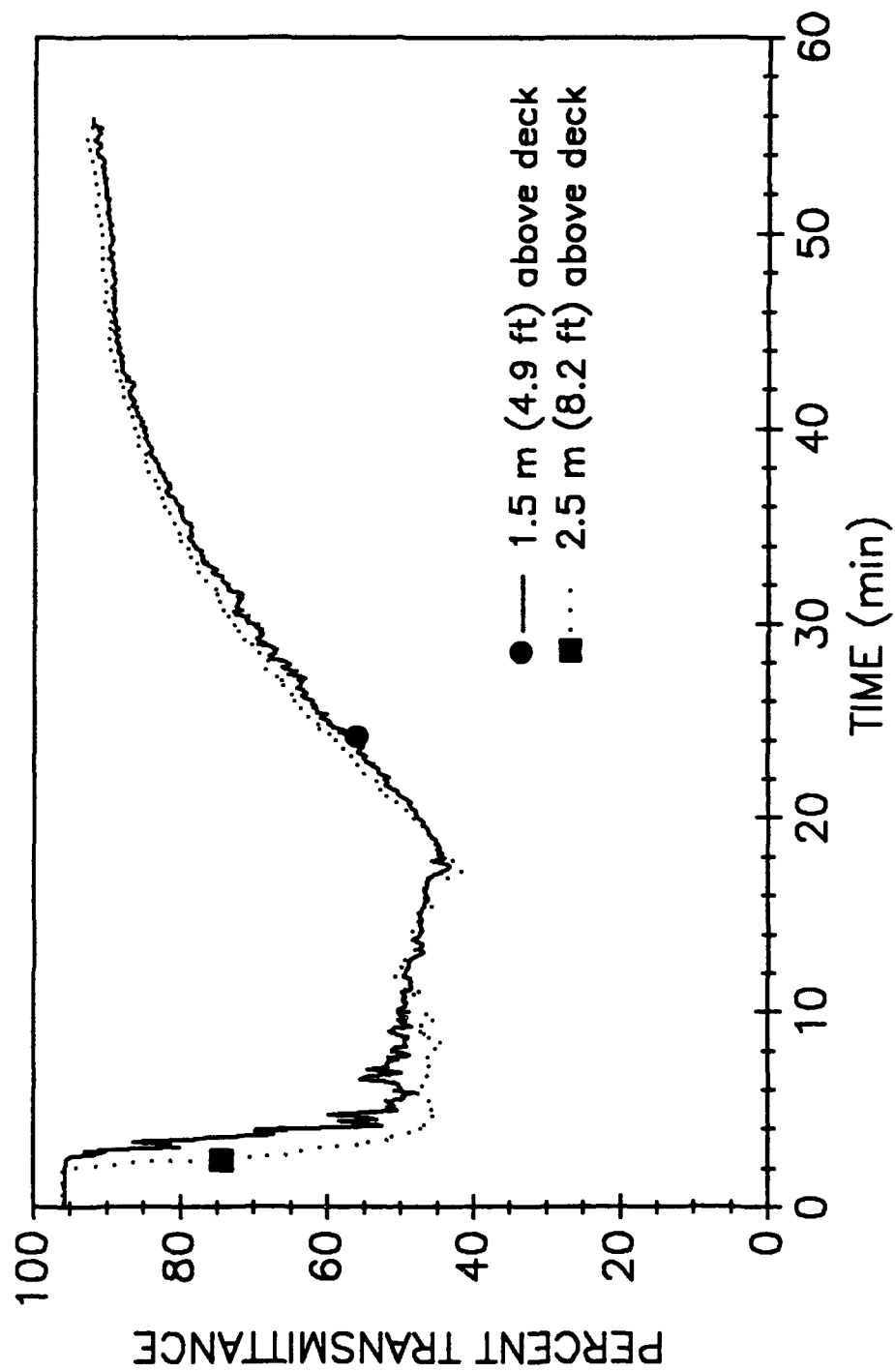


Fig. 25 - Percent transmittance in RICER 1 during FAN\_12  
using Red Devil 25.4 cm (10 in) duct

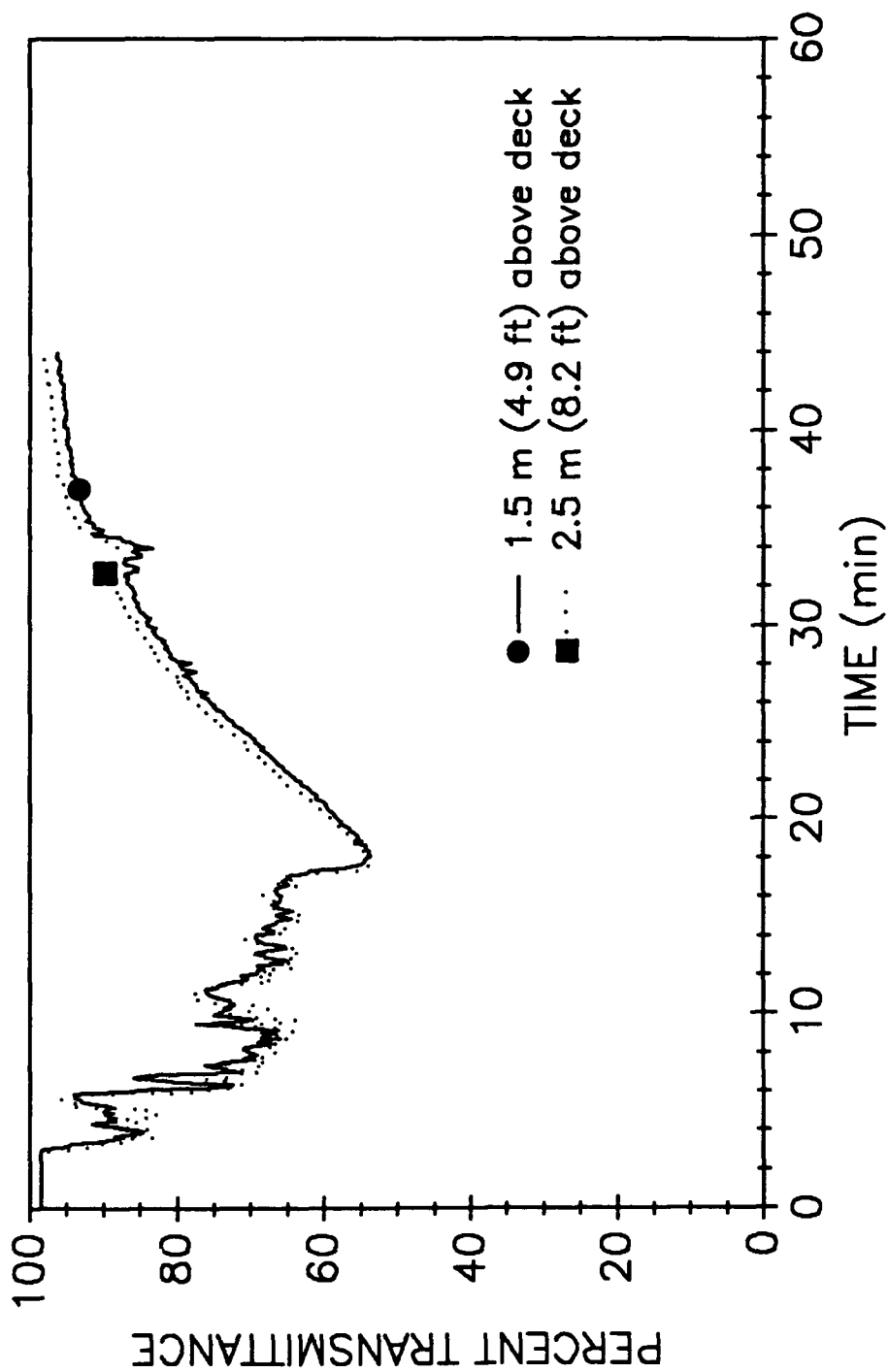


Fig. 26 - Percent transmittance in RICER 1 during FAN\_15  
using RAMFAN 345 kPa (50 psi)

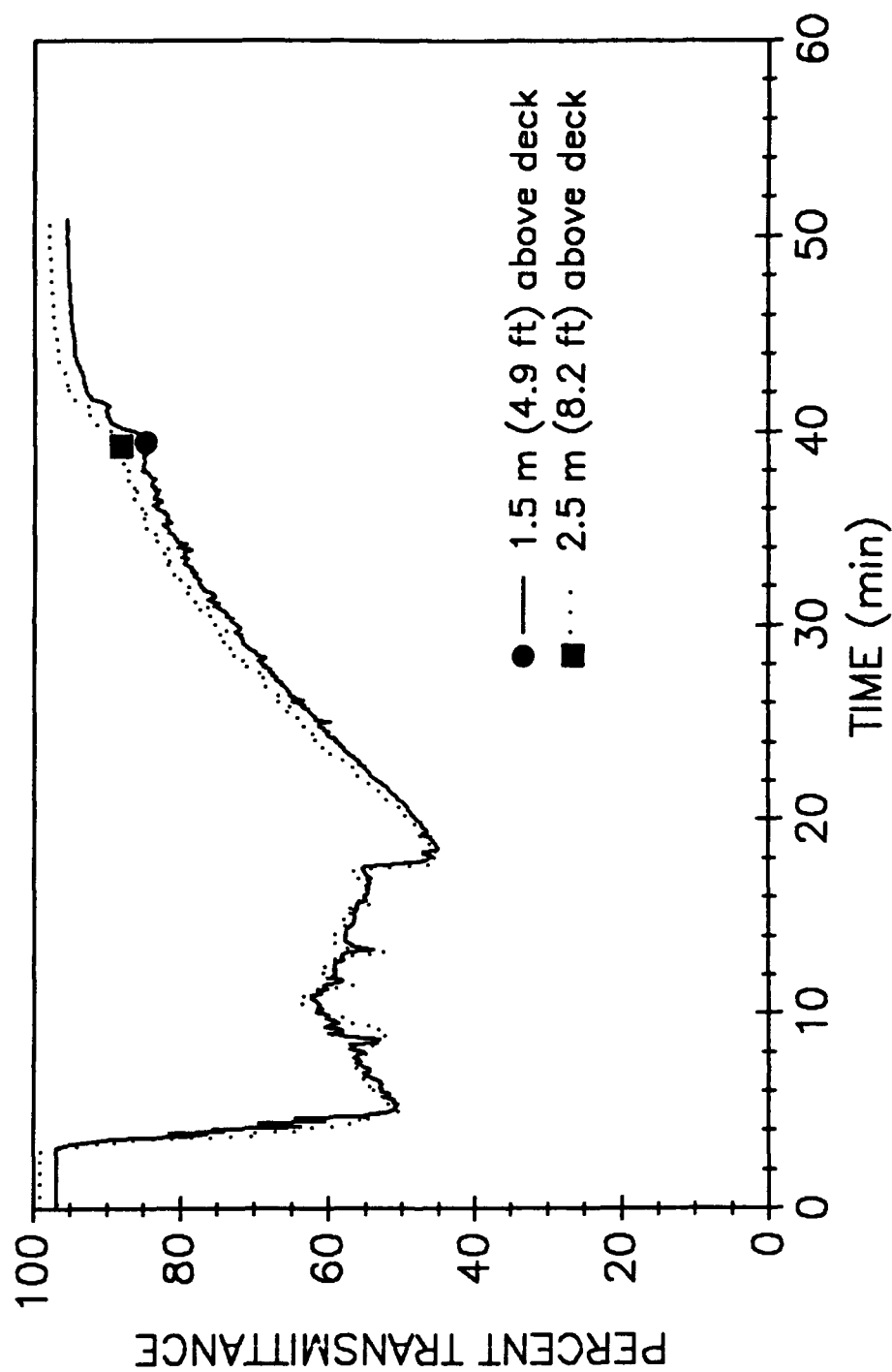


Fig. 27 - Percent transmittance in RICER 1 during FAN\_16  
using Red Devil 25.4 cm (10 in) duct

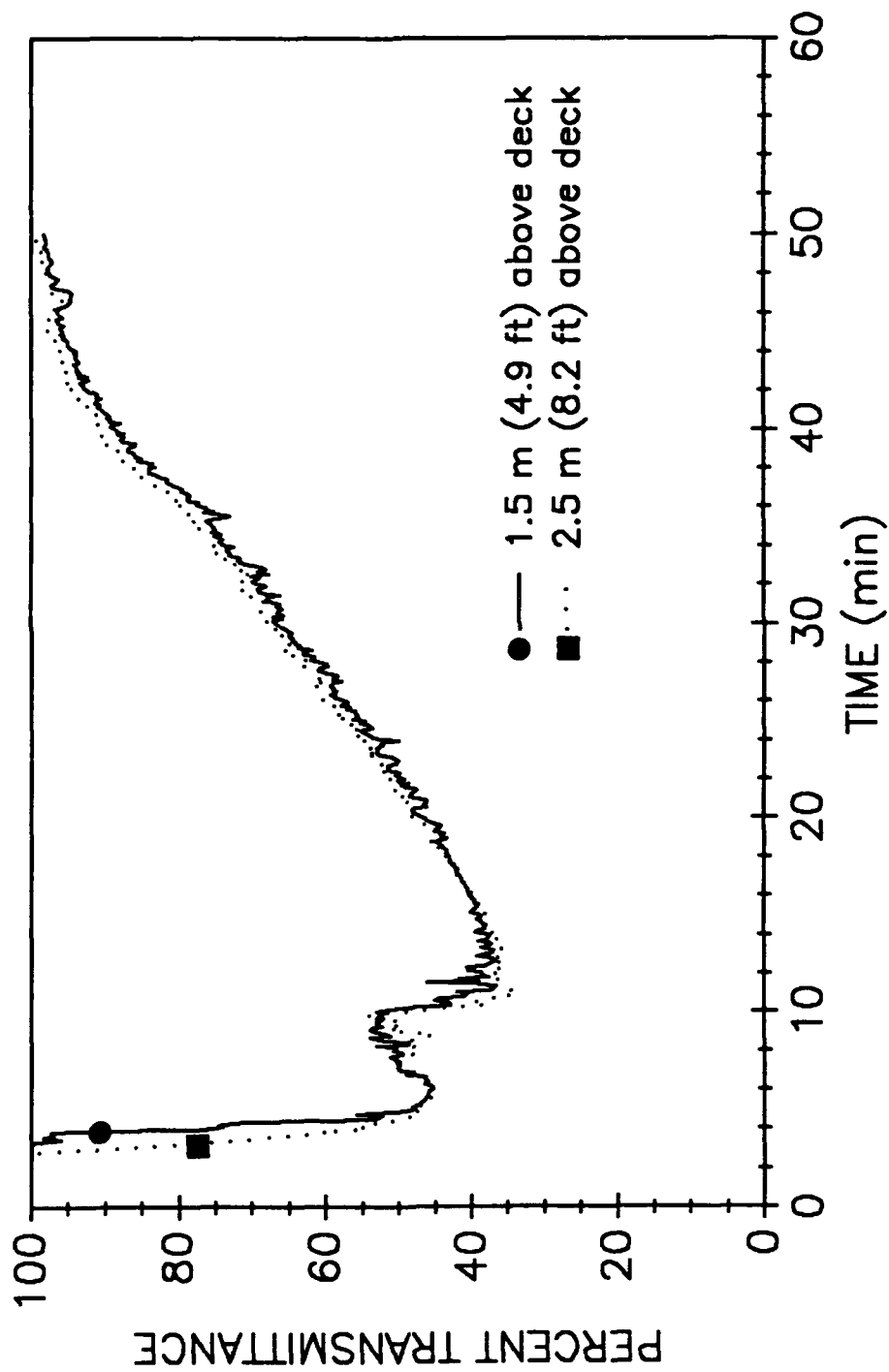


Fig. 28 - Percent transmittance in RICER 1 during FAN\_17  
using Red Devil 20.3 cm (8 in) duct

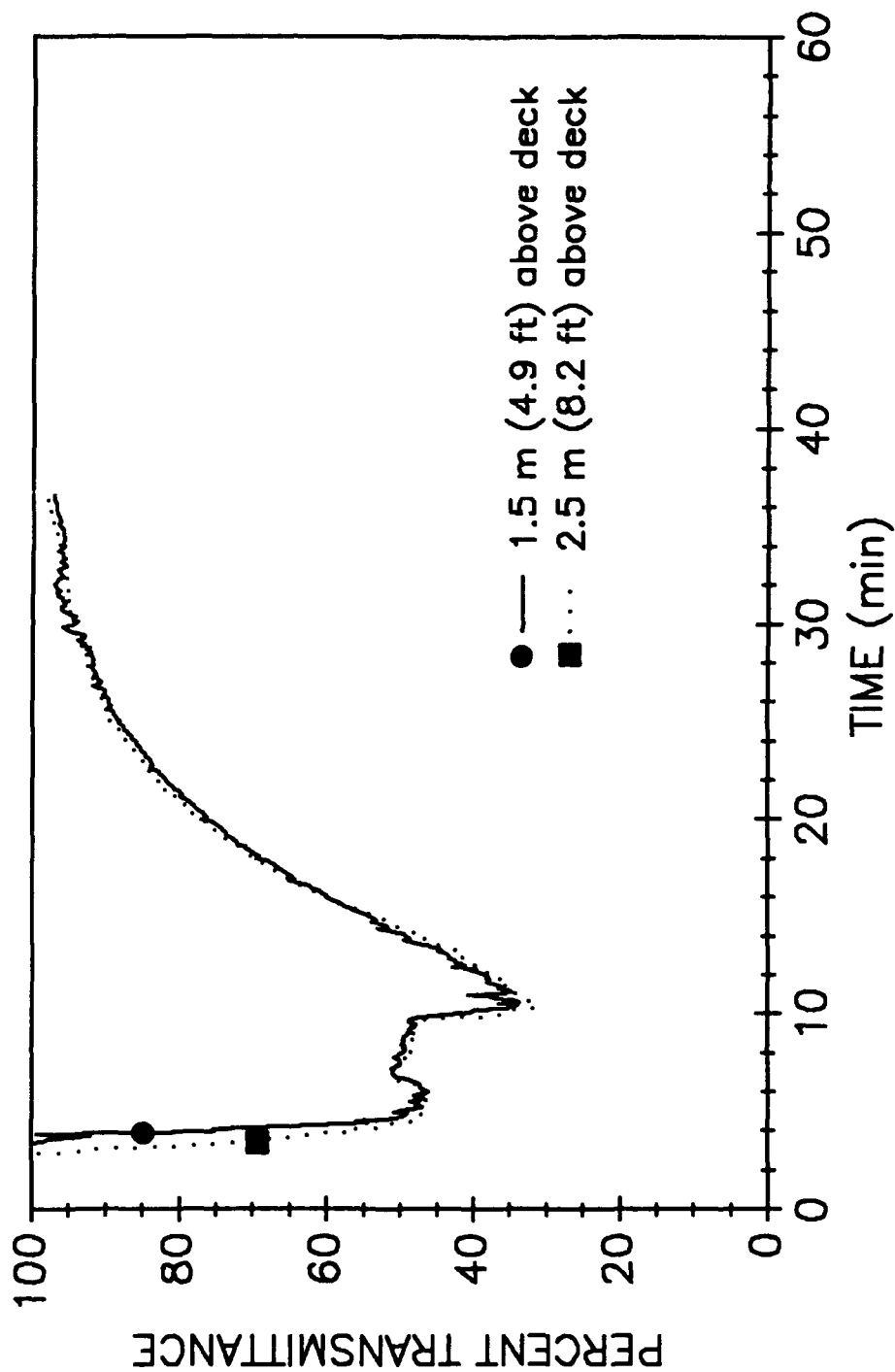


Fig. 29 - Percent transmittance in RICER 1 during FAN\_18  
using RAMFAN 956 kPa (140 psi)

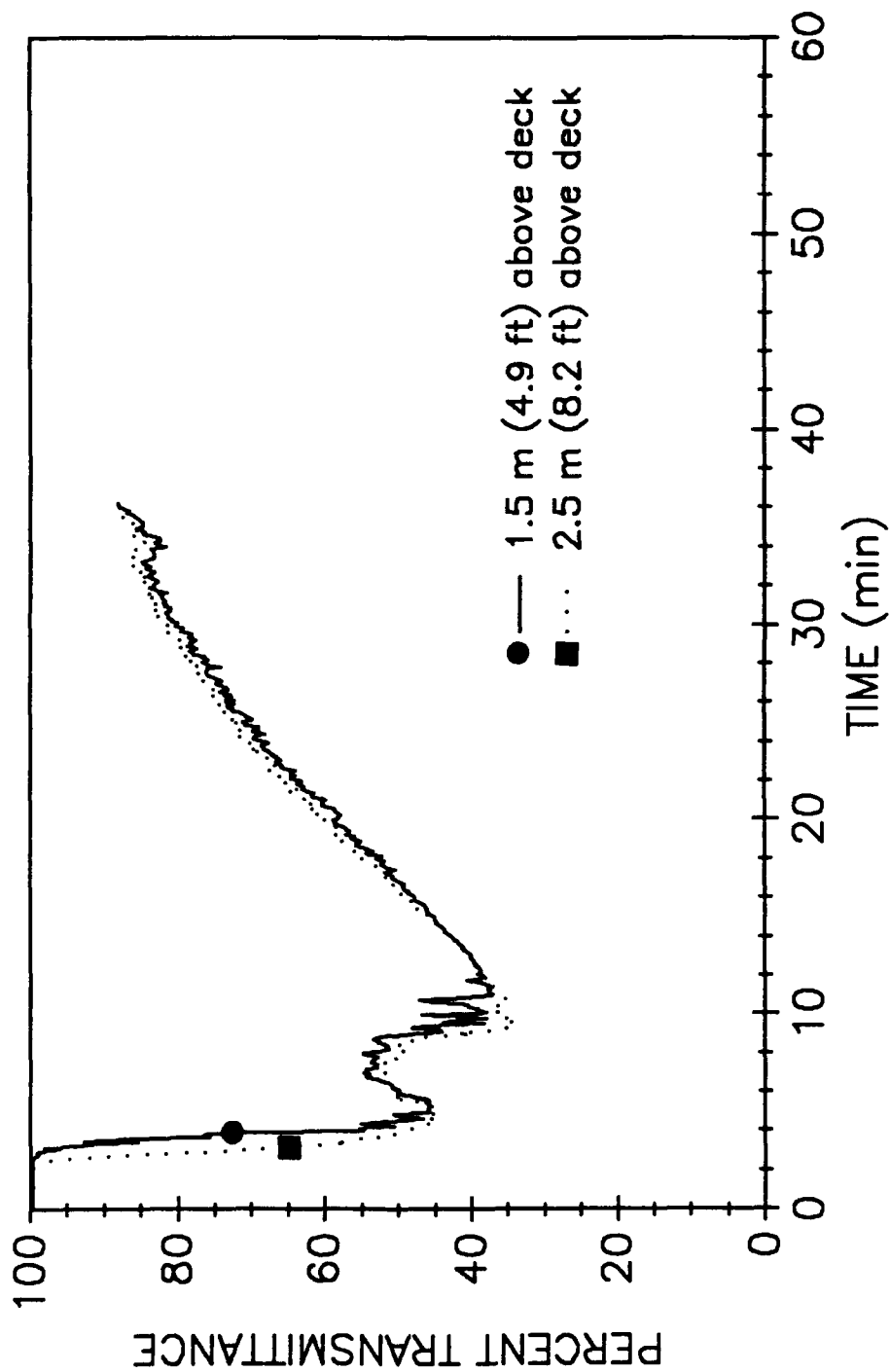


Fig. 30 - Percent transmittance in RICER 1 during FAN\_19  
using Red Devil 25.4 cm (10 in) duct

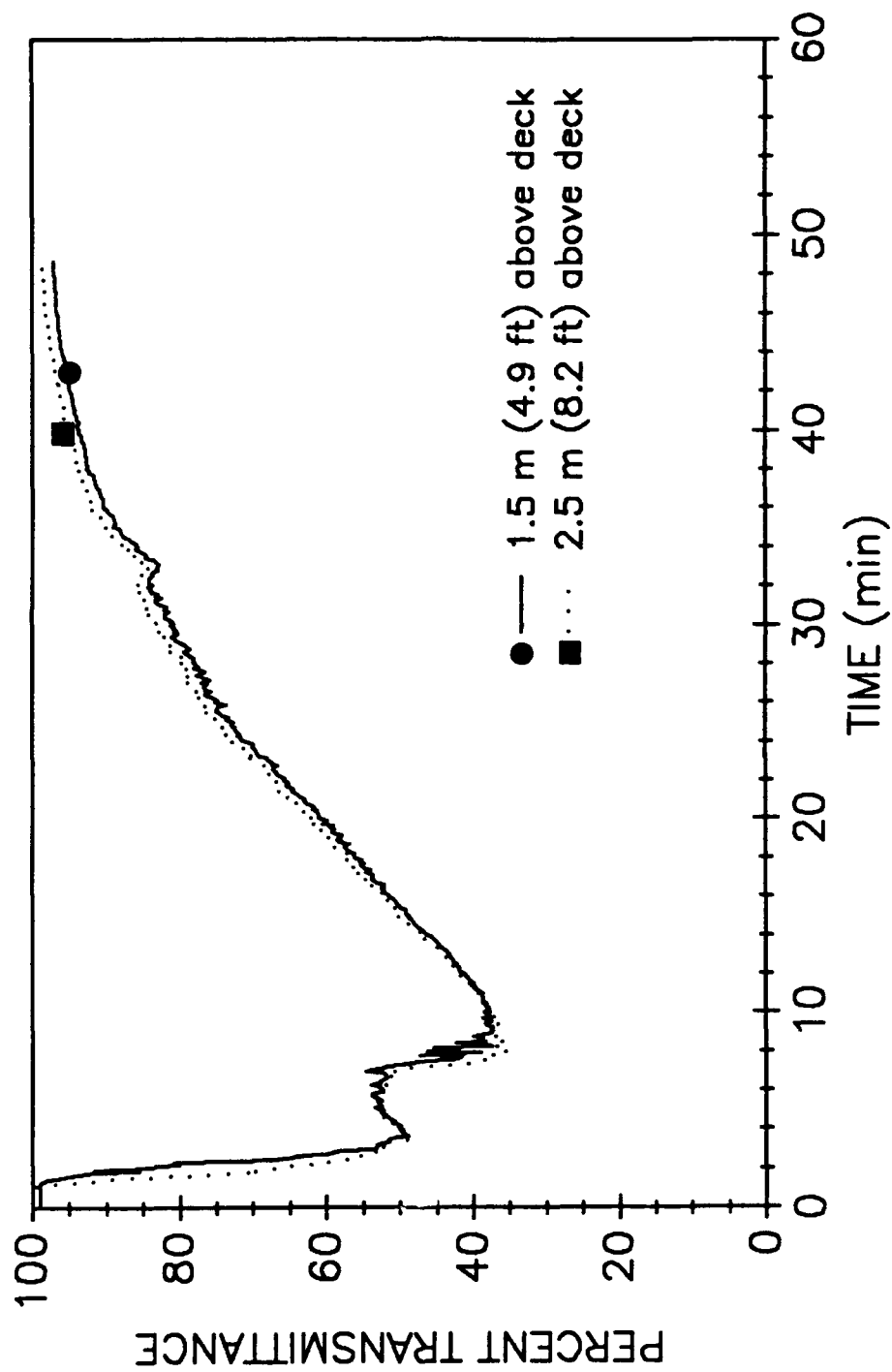


Fig. 31 - Percent transmittance in RICER 1 during FAN\_20  
using RAMFAN 345 kPa (50 psi)

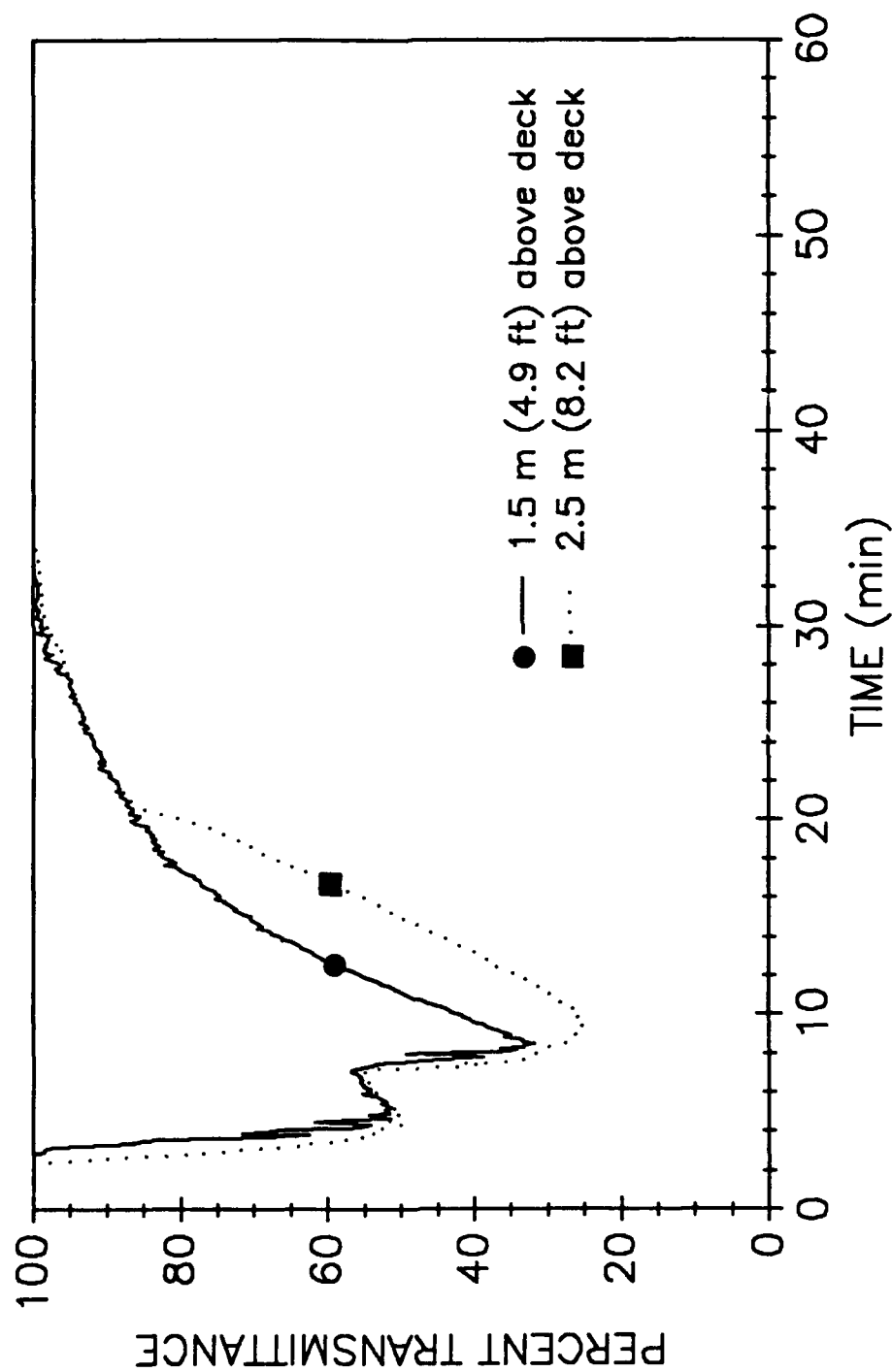


Fig. 32 - Percent transmittance in RICER 1 during FAN\_22  
using RAMFAN 1000 kPa (145 psi)



Figures 33 through 38 show the normalized transmittance for the selected unmanned and manned tests. The smoke meter located 2.5 m (8 ft) above the deck in BERTHING 1 and RICER 1 and at the lintel between BERTHING 1 and 2 were selected as the best representation of the flow of smoke for these tests. The initial negative values in Fig. 35 for the second deck is attributed to the desmoking fan drawing smoke from the third deck, i.e. the initial concentration of smoke in RICER 1 was less than when the fan was activated. The negative values were also observed in the manned tests at the second deck (Fig. 38). From Figs. 33 through 35, it is shown that the Red Devil with the 25.4 cm (10 in.) duct improved the transmittance more quickly than the Red Devil 20.3 cm (8 in.) duct. For example, in Fig. 33 at 10 minutes, the transmittance, using the Red Devil 25.4 cm (10 in.), is 58% recovered compared to the transmittance of the Red Devil 20.3 cm (8 in.) which is only 38% recovered. When comparing the Red Devil 25.4 cm (10 in.) to the RAMFAN at low pressures (345 kPa (50 psi)), the two fans were essentially comparable as seen in Fig. 33 and 37. However, the RAMFAN at high pressures (965 kPa (145 psi)) improved the transmittance faster than the other fans tested (Figs. 36 and 37).

Table 4 shows a comparison of the visibility obtained from the light string and the smoke meters on the third deck. Quintiere and Lawson [10] estimated visibility by using a correlation derived from Rasbash, Jin and Lopez. These relationships were developed from experiments using various lighting materials such as a lamp or an illuminated sign with different types of smoke. Distances (in meters) were measured as to how far one could see the lighted material through the smoke. These numbers were plotted against the optical density per path length of smoke ( $m^{-1}$ ). The visibility for a selected number of tests for this series were confirmed with the string of lights hung in BERTHING 1 and RICER 1. Considering that the heights of the smoke meters and the light strings were different, the visibilities obtained from the light strings and the approximation from the smoke meter data using the Rasbash correlation were comparable. Note, this table should not be used to compare the visibility between fans since it does not account for the varying concentrations of smoke between tests.

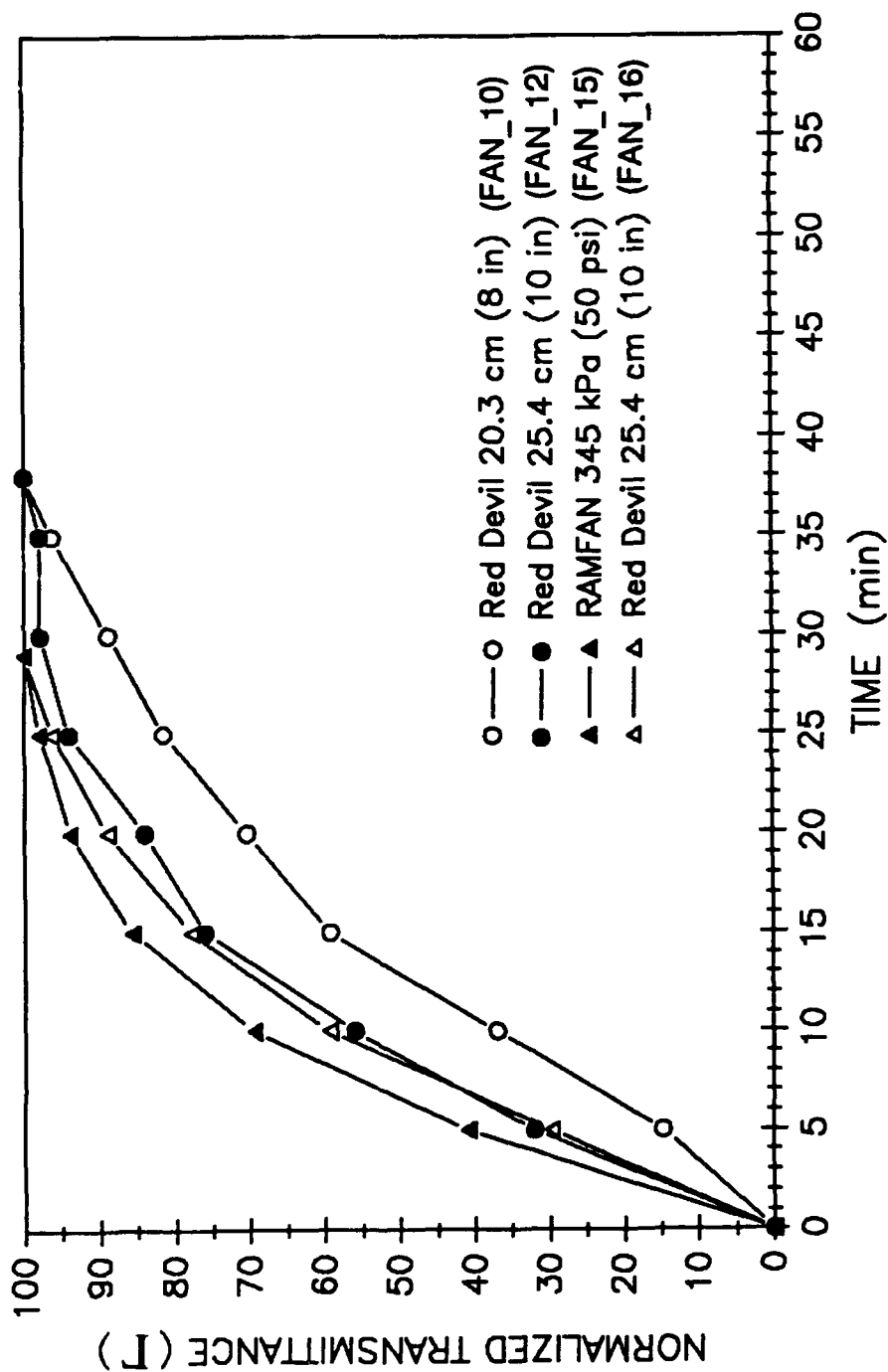


Fig. 33 - Recovery of normalized transmittance at 3rd deck -  
2.5 m level after fan is activated

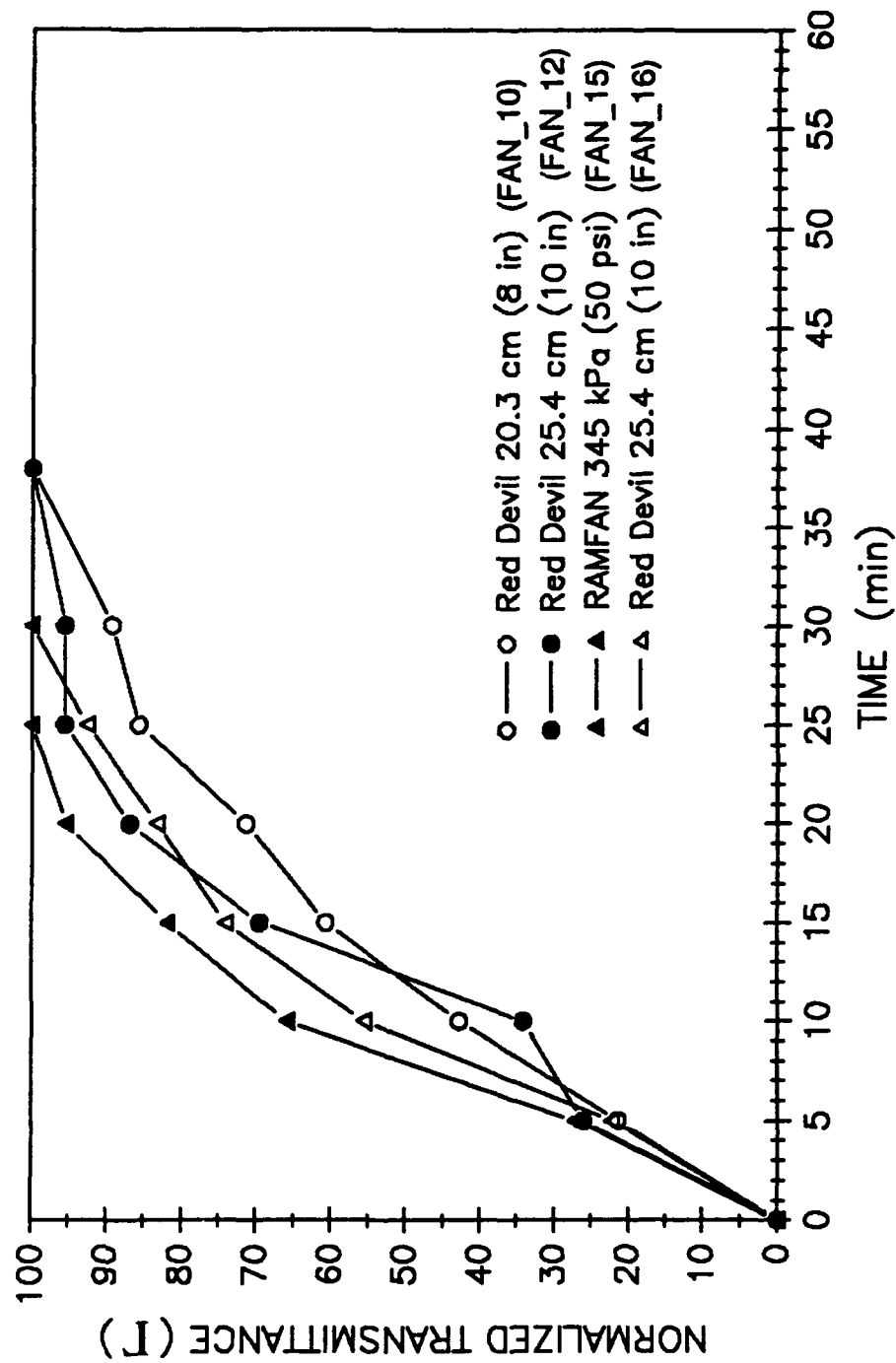


Fig. 34 - Recovery of normalized transmittance at 3rd deck -  
intel after fan is activated

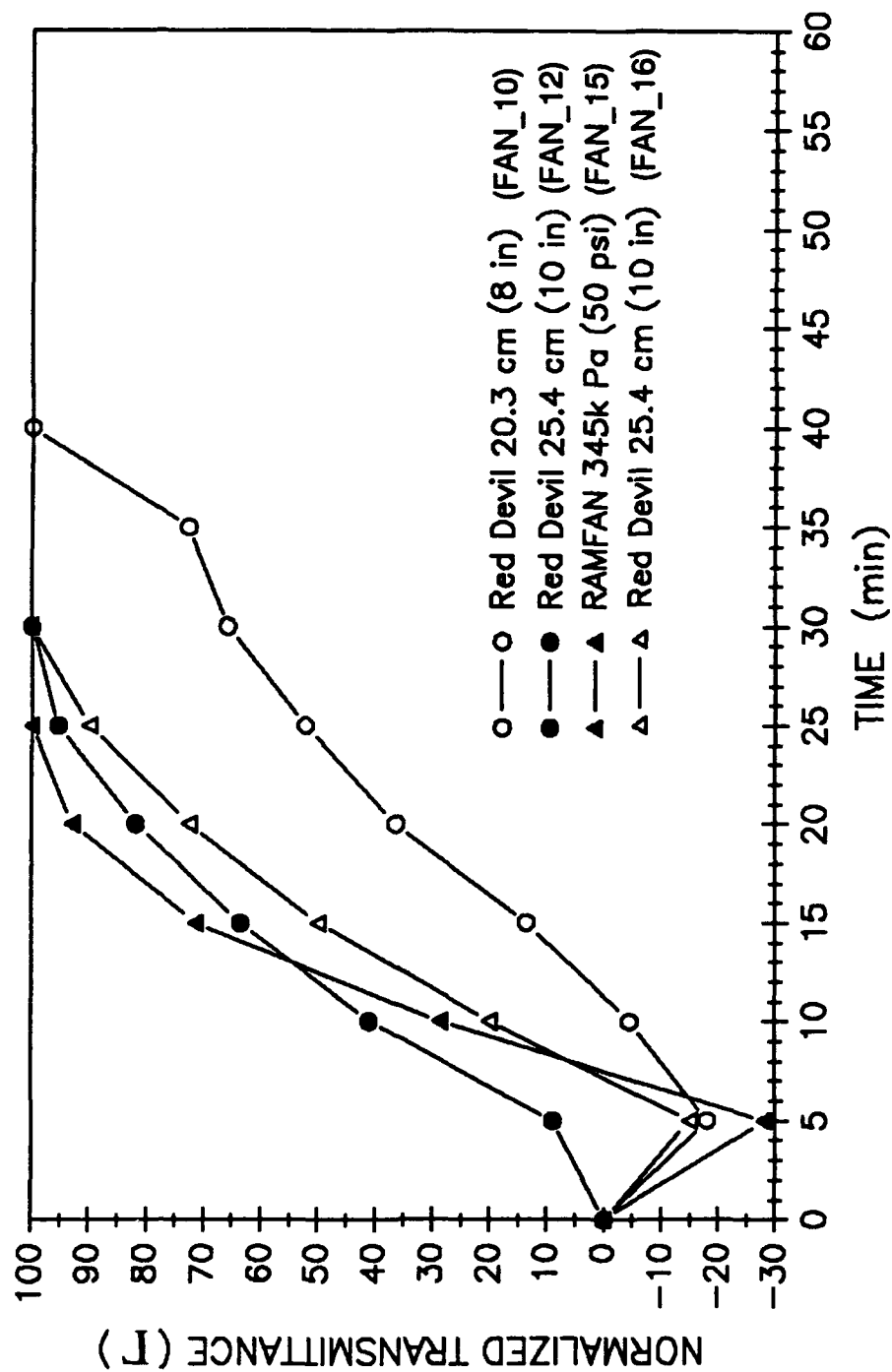


Fig. 35 - Recovery of normalized transmittance at 2nd deck -  
2.5 m level after fan is activated

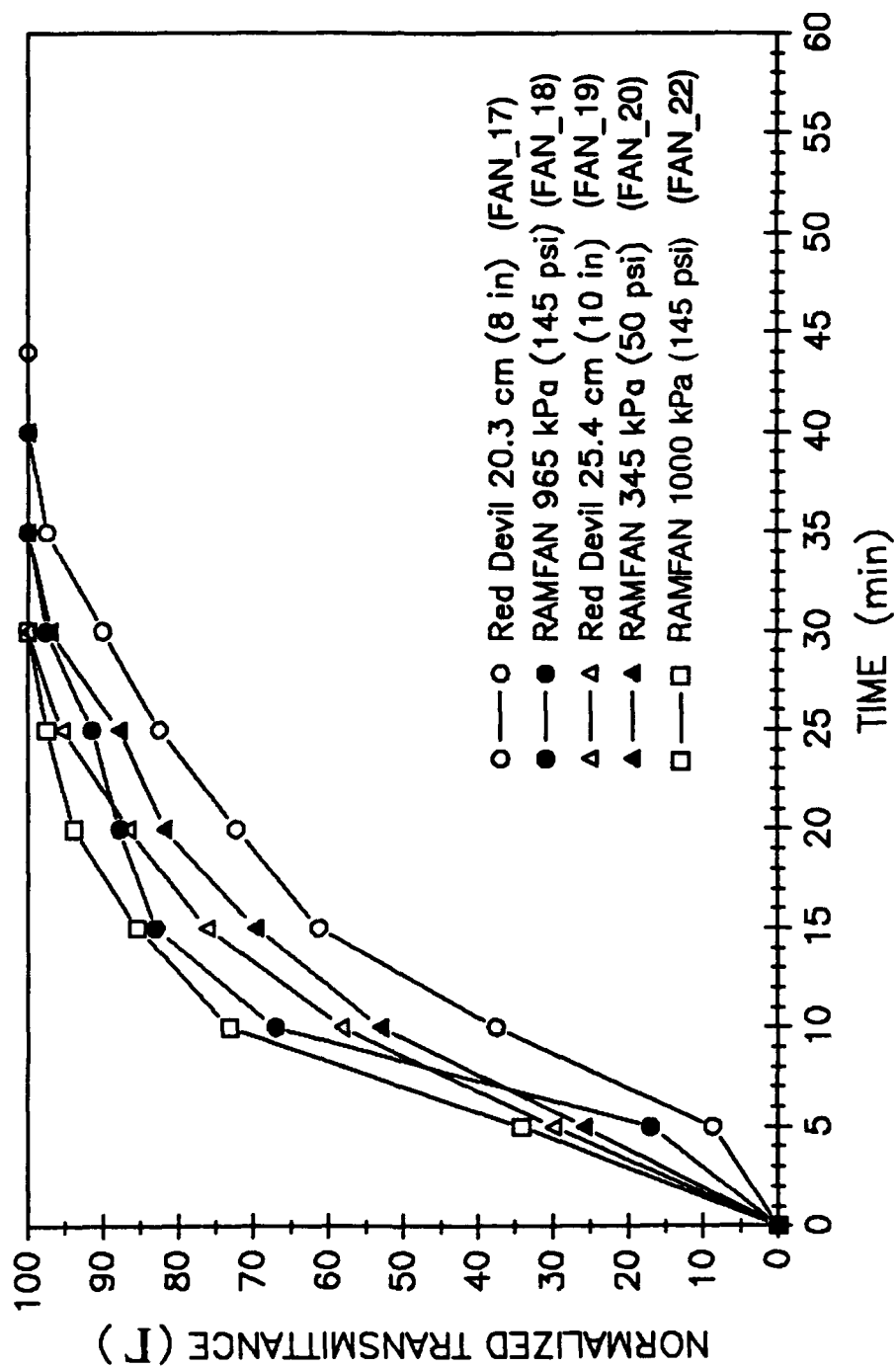


Fig. 36 - Recovery of normalized transmittance at 3rd deck -  
2.5 m level after fan is activated

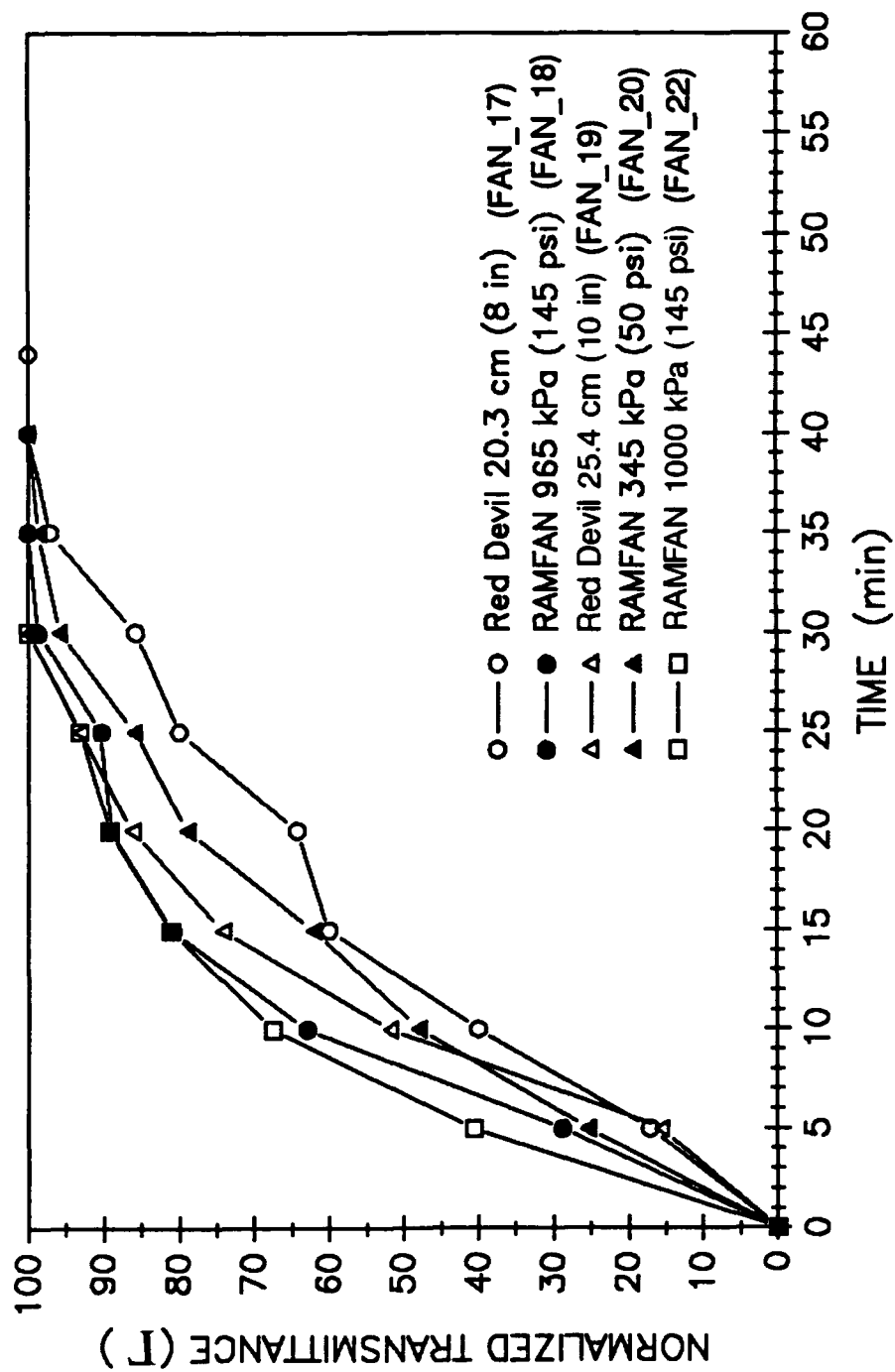


Fig. 37 - Recovery of normalized transmittance at 3rd deck -  
lintel after fan is activated

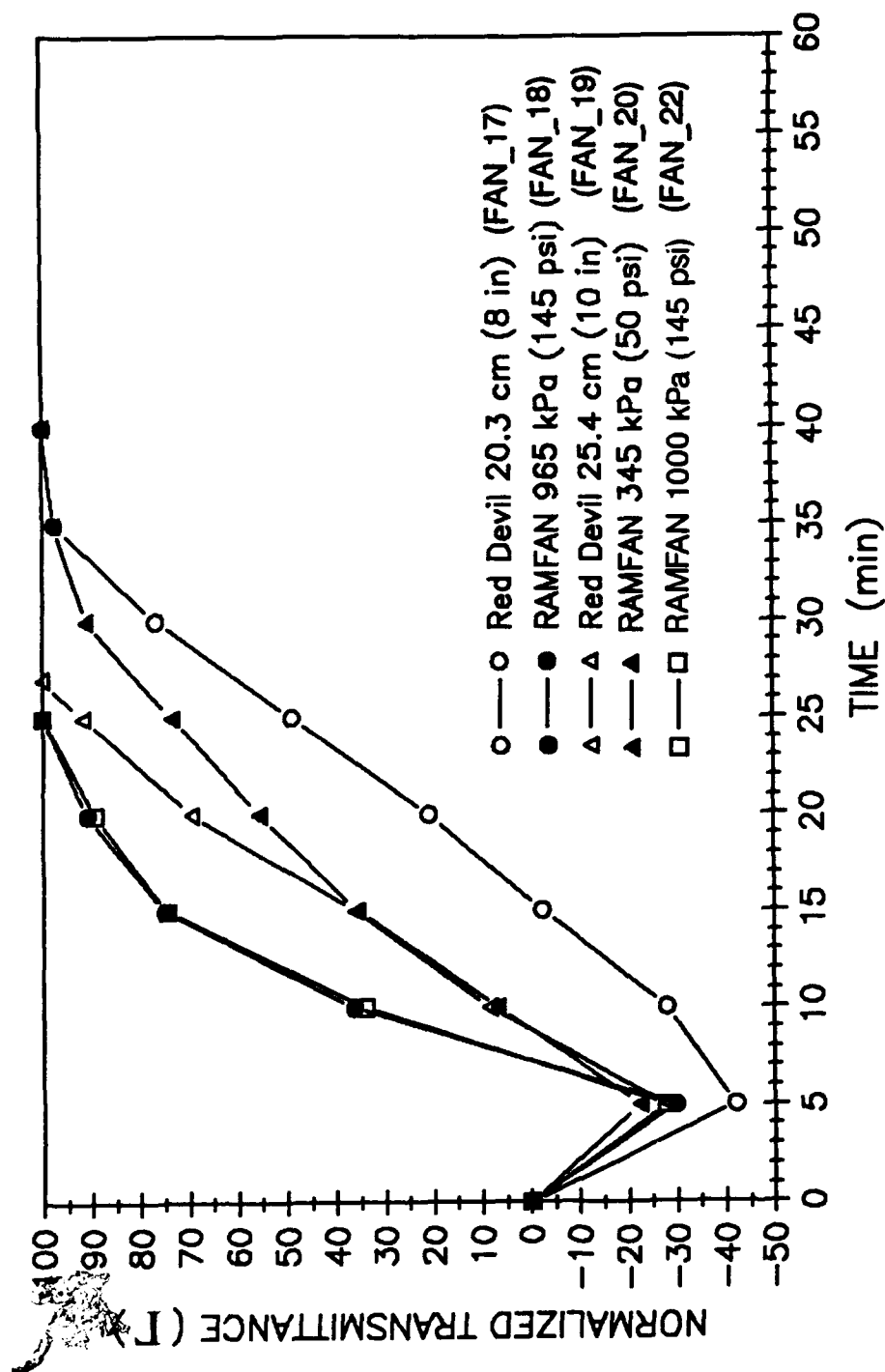


Fig. 38 - Recovery of normalized transmittance at 2nd deck - 2.5 m level after fan is activated

Table 4. Visibility Comparison of Smoke Meters and Lights

<u>Smoke Meter Location</u>	<u>Time after activation of fan (min.)</u>	<u>Light Visibility (estimated) (m (ft))</u>		<u>Smoke Meter Visibility (estimated) (m (ft))</u>	
Red Devil using 20.3 cm (8 in.) duct (FAN_17)					
BERTHING 1 2.54 m level	1.5	3	(9.8)	2	(6.6)
	5	4	(13.1)	3	(9.8)
	6	5	(16.4)	3	(9.8)
BERTHING 1 Lintel	1.5	3	(9.8)	2	(6.6)
	5	4	(13.1)	5	(16.4)
	6	5	(16.4)	3	(9.8)
Red Devil using 25.4 cm (10 in.) duct (FAN_19)					
BERTHING 1 2.54 m level	2	3	(9.8)	3	(9.8)
	7	4	(13.1)	5	(16.4)
	9	5	(16.4)	5	(16.4)
BERTHING 1 Lintel	2	3	(9.8)	3	(9.8)
	7	4	(13.1)	4	(13.1)
	9	5	(16.4)	5	(16.4)



Table 4. Visibility Comparison of Smoke Meters and Lights (Continued)

Smoke Meter Location	Time after activation of fan (min.)	Light Visibility (estimated) <u>(m (ft))</u>		Smoke Meter Visibility (estimated) <u>(m (ft))</u>	
RAMFAN 345 kPa (50 psi) (FAN_20)					
BERTHING 1 2.54 m level	0.5	2	(6.6)	3	(9.8)
	4	3	(9.8)	4	(13.1)
	7	4	(13.1)	5	(16.4)
	9	5	(16.4)	5	(16.4)
BERTHING 1 Lintel	0.5	2	(6.6)	3	(9.8)
	4	3	(9.8)	3	(9.8)
	7	4	(13.1)	4	(13.1)
	9	5	(16.4)	5	(16.4)
RAMFAN 965 kPa (140 psi) (FAN_22)					
BERTHING 1 2.54 m level	1	2	(6.6)	2	(6.6)
	2	3	(9.8)	2	(6.6)
	5	4	(13.1)	4	(13.1)
	7	5	(16.4)	5	(16.4)
BERTHING 1 Lintel	1	2	(6.6)	2	(6.6)
	2	3	(9.8)	3	(9.8)
	5	4	(13.1)	4	(13.1)
	7	5	(16.4)	5	(16.4)

### 8.3.2 Gas Recovery

Oxygen measurements were taken at the same locations as the smoke meters in BERTHING 1 and RICER 1. Figures 39 through 56 are the oxygen concentrations for the representative tests. As in the smoke data, the time before ignition is shown. Figures 57 through 60 show the recovery of oxygen in BERTHING 1 and RICER 1 for selected unmanned and manned static tests. As in the recovery of transmittance, the recovery of oxygen varied from test to test also. The same technique used to analyze the transmittance was used to analyze the recovery of oxygen. The equation used is as follows.

$$\Phi = \frac{O_n - O_i}{O_f - O_i} \times 100 \quad (2)$$

From Fig. 59, the water motor fan at 965 kPa (145 psi) recovers 90% of the oxygen in 5 minutes as compared to the Red Devil 20.3 (8 in.) where only 70% of oxygen is recovered in the first 5 minutes after activation of the fan. The recovery of oxygen between the Red Devil 25.4 (10 in.) and the WMF at 345 kPa (50 psi) is approximately the same. Figure 60 shows the same trends of the WMF at high pressure recovering the oxygen concentration much faster than the other tests. Table 5 compares the oxygen recovery data in Fig. 59.

Table 5. Comparison of Oxygen Concentrations Using Various  
Desmoking Fans for FAN\_17 through FAN\_22

	<u>2 min.</u>	<u>5 min.</u>	<u>10 min.</u>
WMF 965 kPa (145 psi)	60%	90%	96%
WMF 145 kPa (50 psi)	58%	72%	86%
Red Devil 25.4 cm (10 in.)	56%	72%	84%
Red Devil 20.3 cm (8 in.)	56%	72%	80%

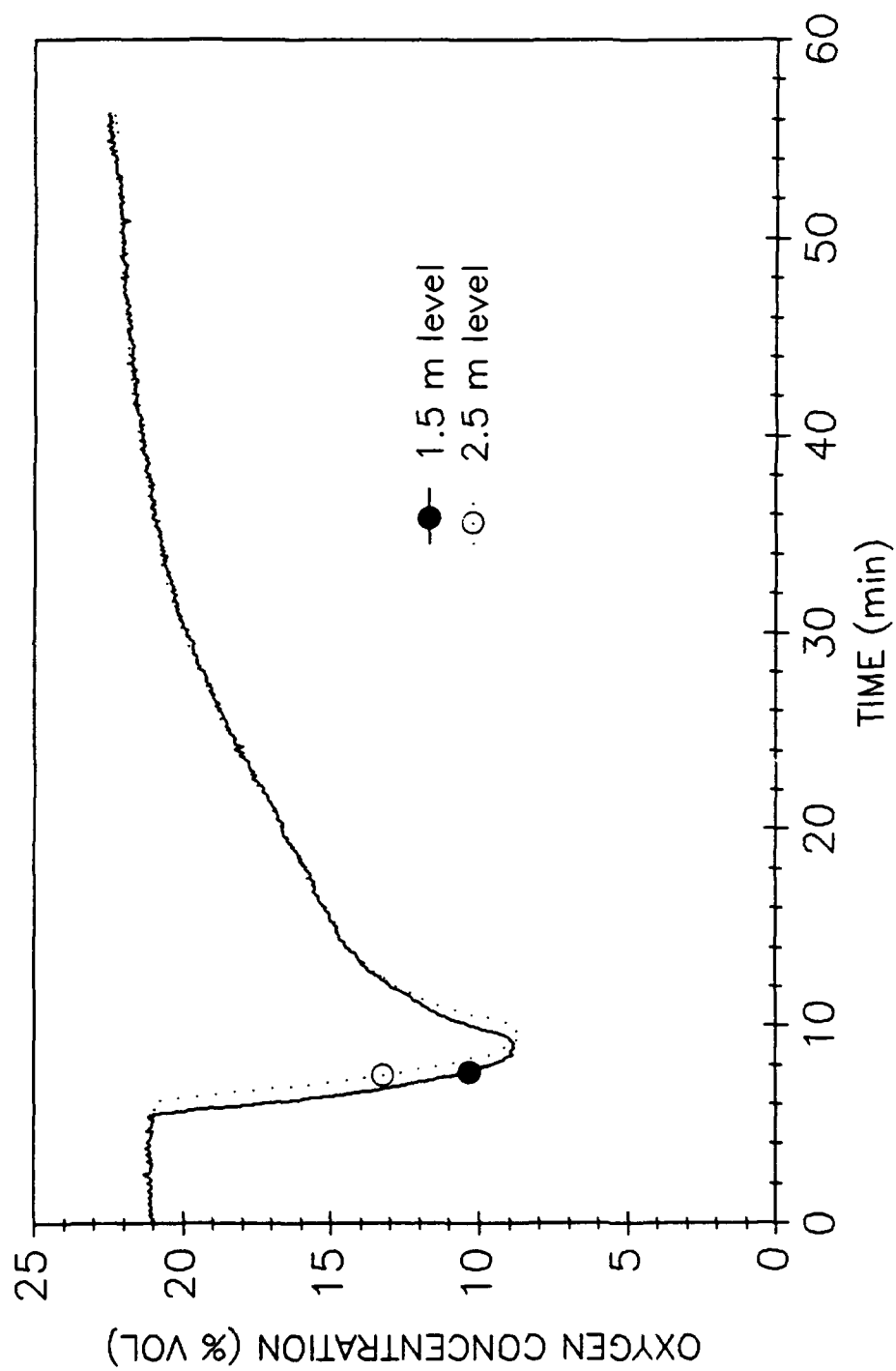


Fig. 39 - Oxygen concentrations in BERTHING 1. during FAN\_10  
using Red Devil 20.3 cm (8 in) duct

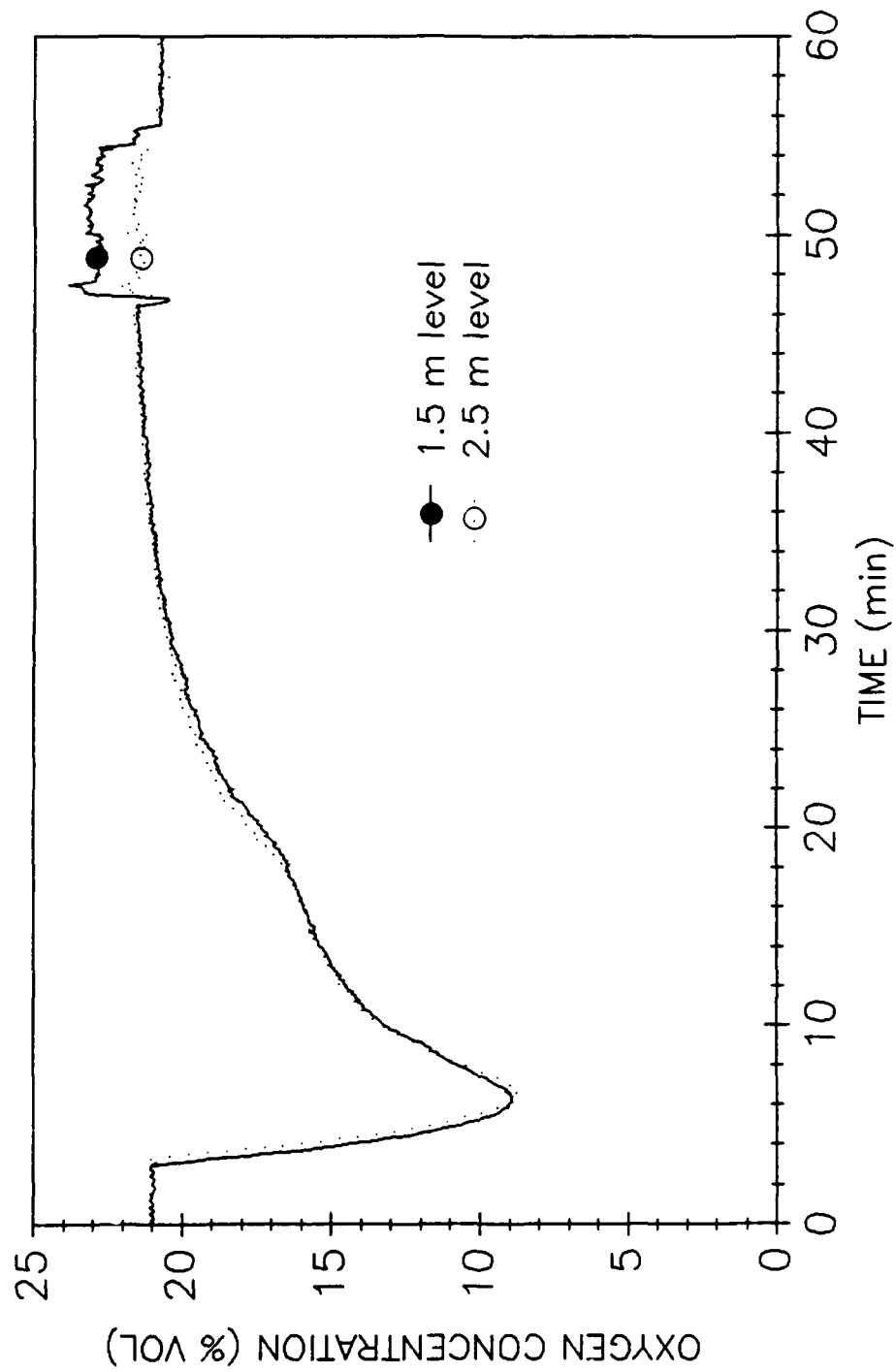


Fig. 40 - Oxygen concentrations in BERTHING 1 during FAN\_12  
using Red Devil 25.4 cm (10 in) duct

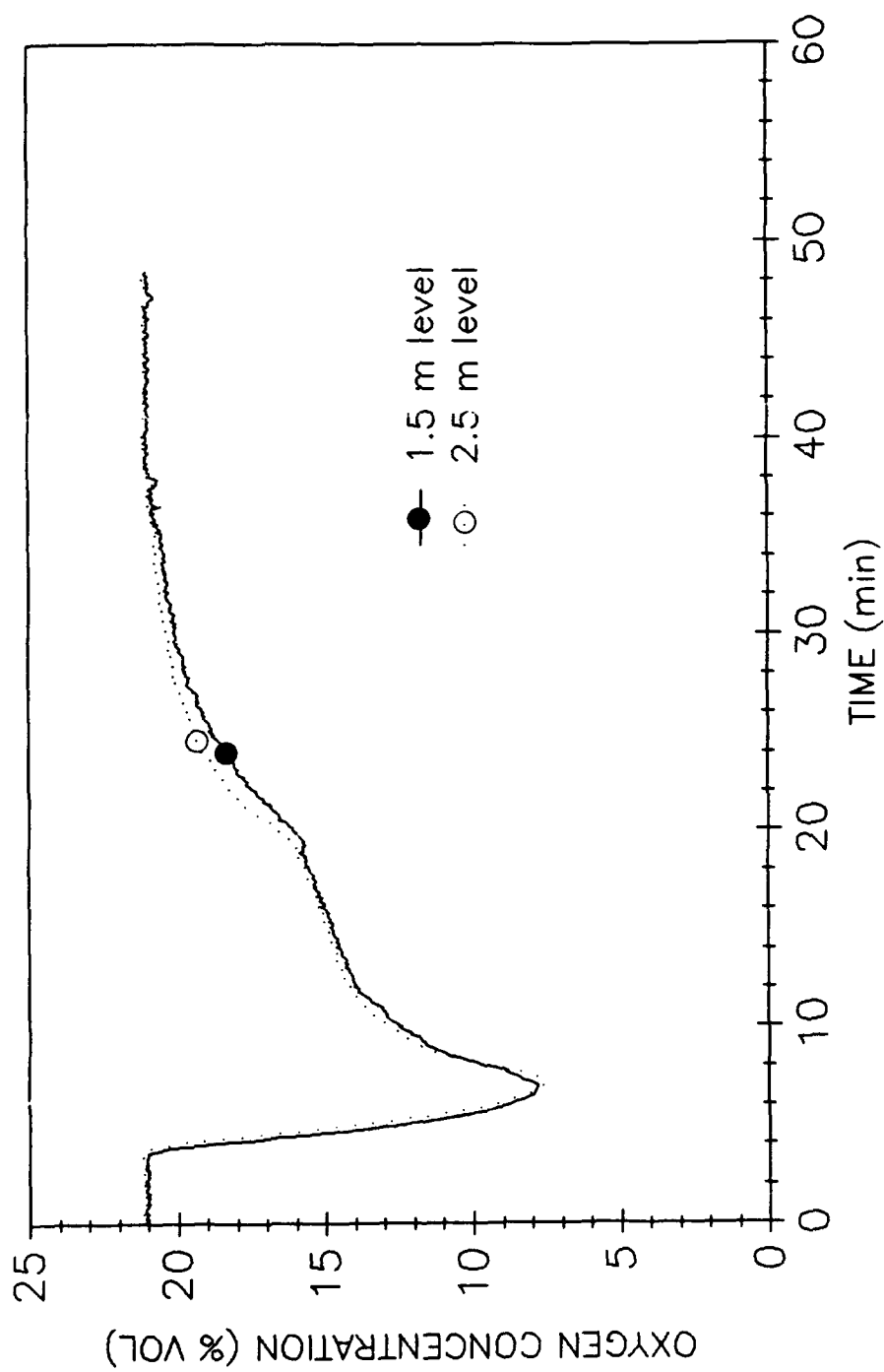


Fig. 41 - Oxygen concentrations in BERTHING 1 during FAN\_15  
using RAMFAN 345 kPa (50 psi)

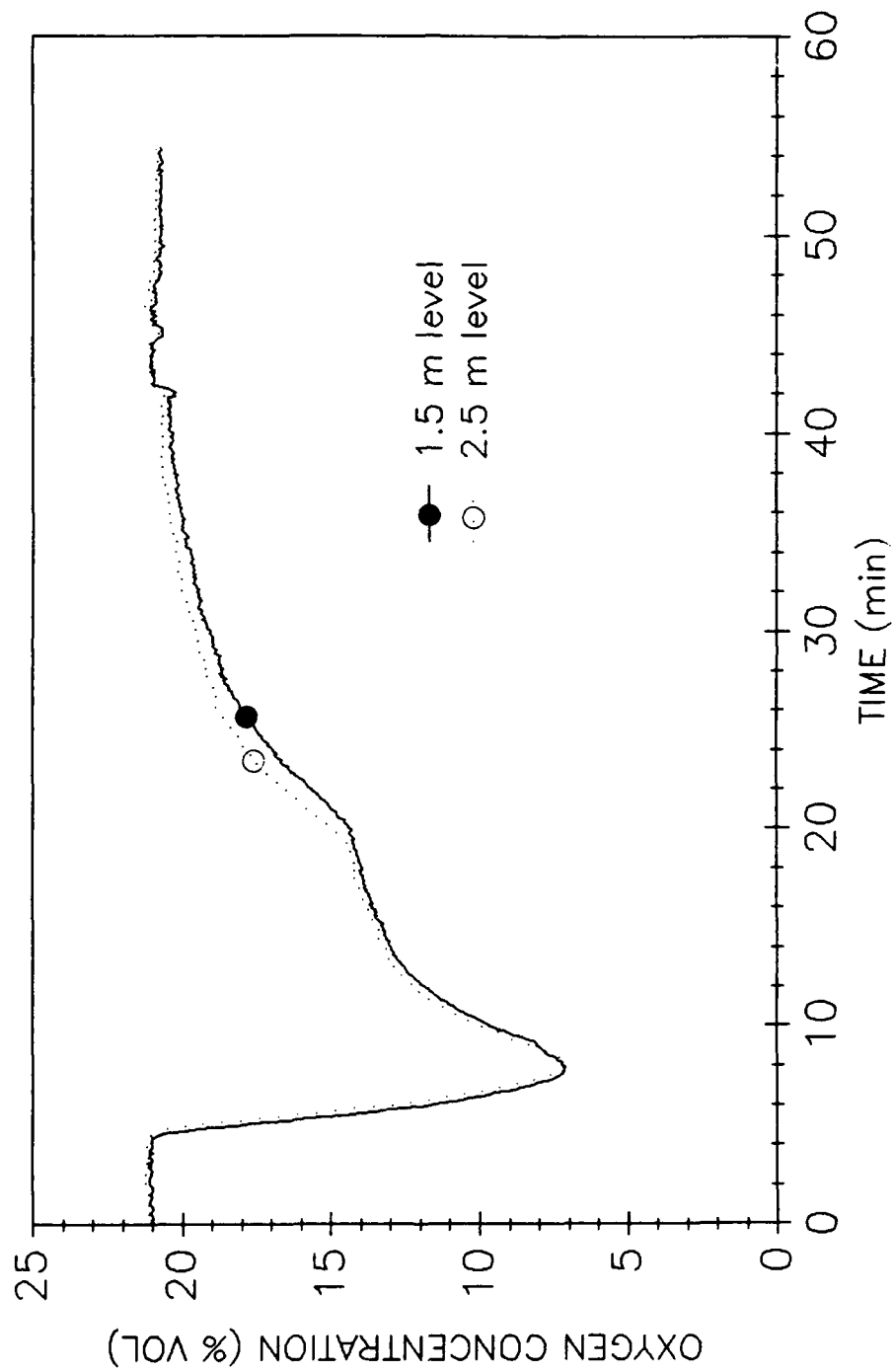


Fig. 42 - Oxygen concentrations in BERTHING 1 during FAN\_16  
using Red Devil 25.4 cm (10 in) duct

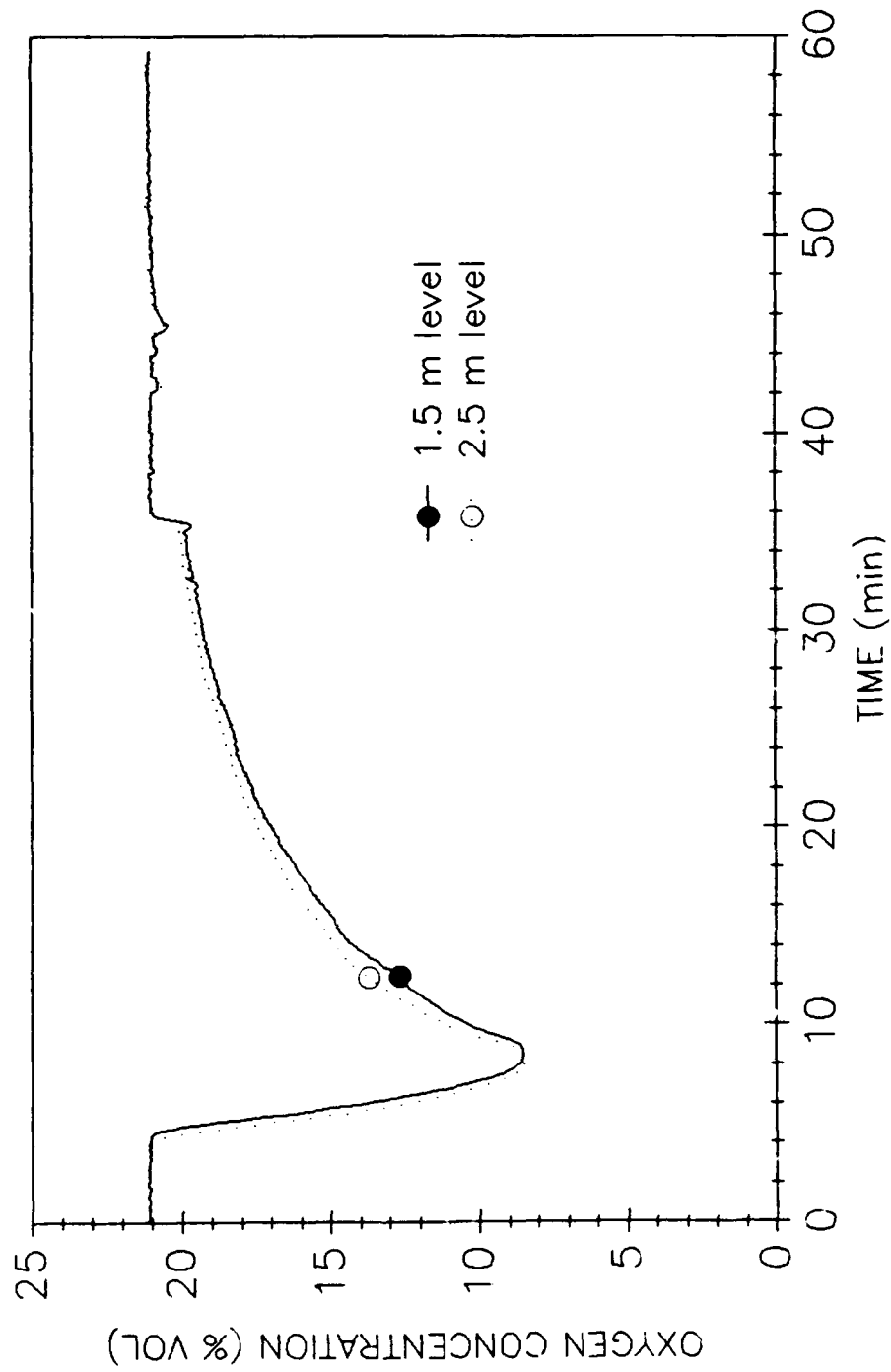


Fig. 43 - Oxygen concentrations in BERTHING 1 during FAN\_17  
using Red Devil 20.3 cm (8 in) duct

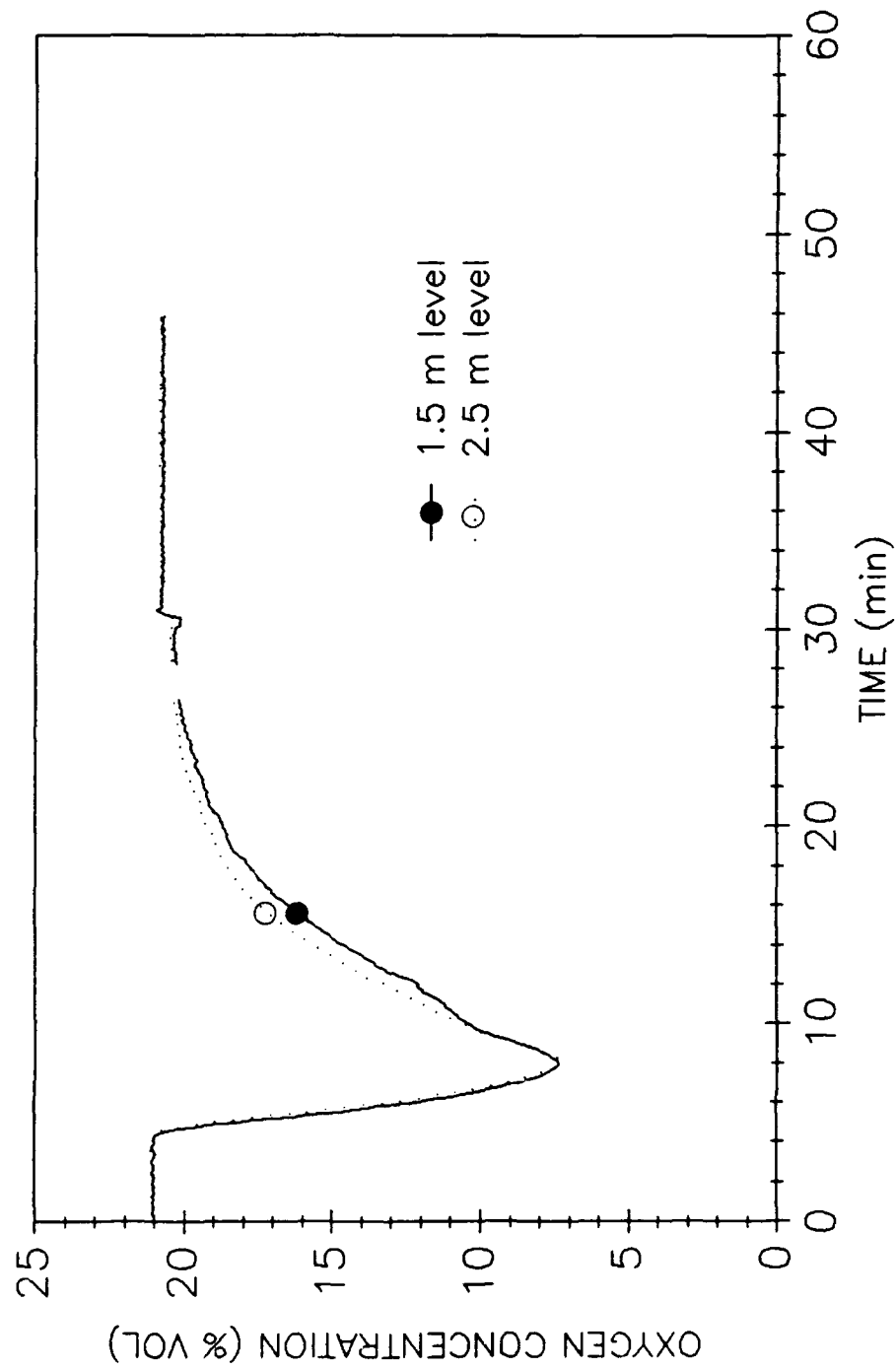


Fig. 44 - Oxygen concentrations in BERTHING 1 during FAN\_18  
using RAMFAN 956 kPa (140 psi)



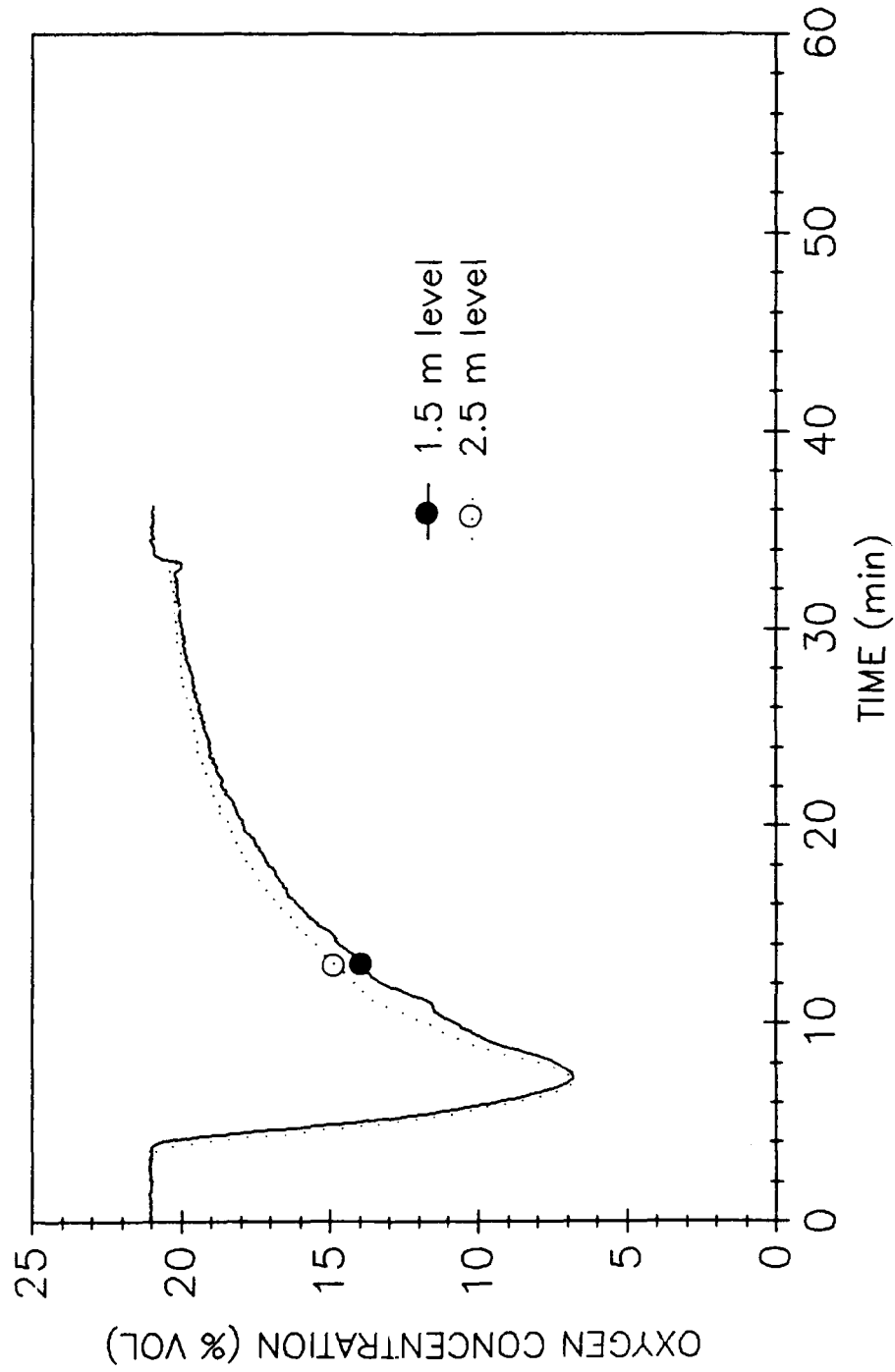


Fig. 45 - Oxygen concentrations in BERTHING 1 during FAN\_19  
using Red Devil 25.4 cm (10 in) duct

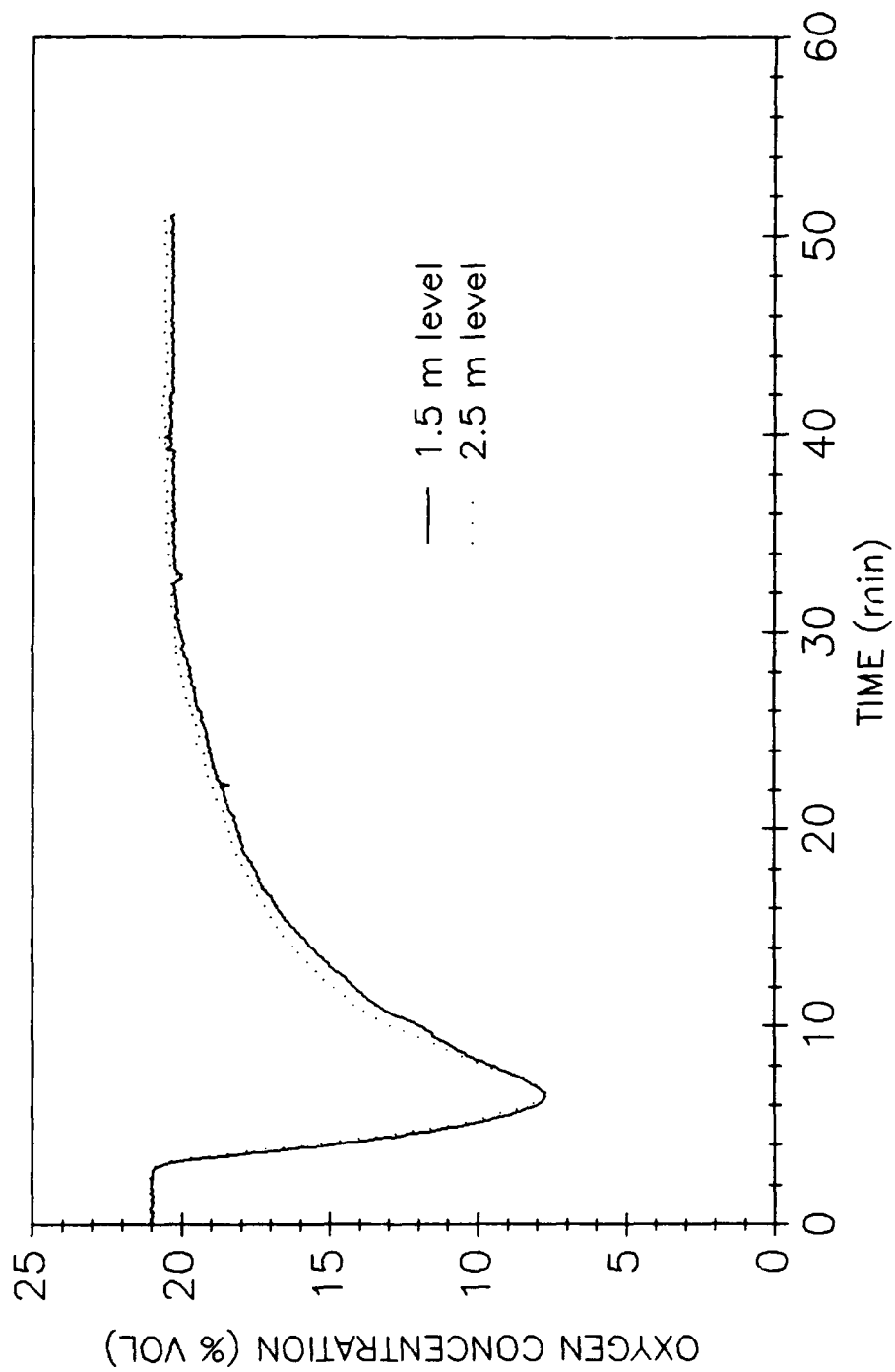


Fig. 46 - Oxygen concentrations in BERTHING 1 during FAN\_20  
using RAMFAN 345 kPa (50 psi)

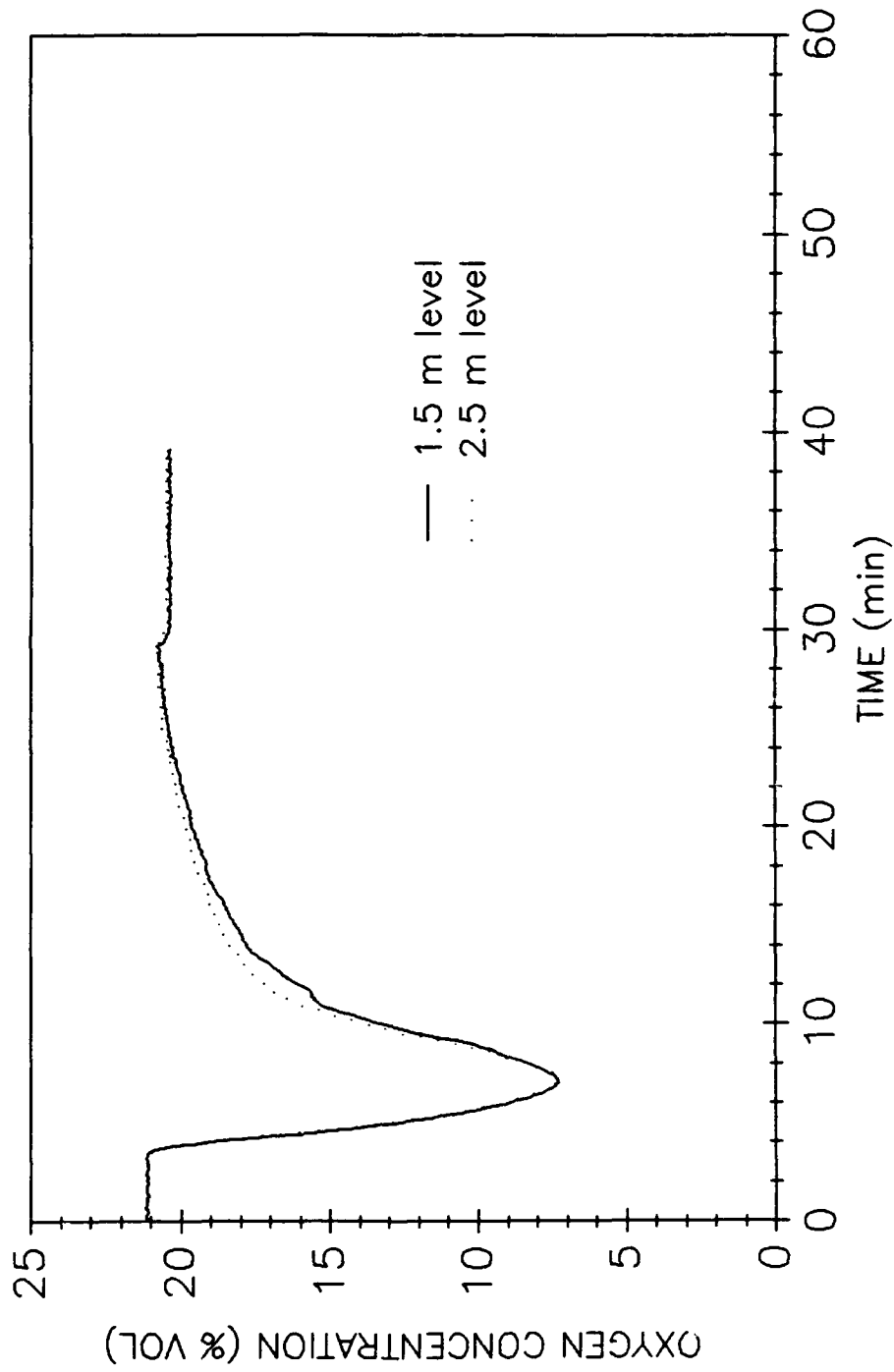


Fig. 47 - Oxygen concentrations in BERTHING 1 during FAN\_22  
using RAMFAN 1000 kPa (145 psi)

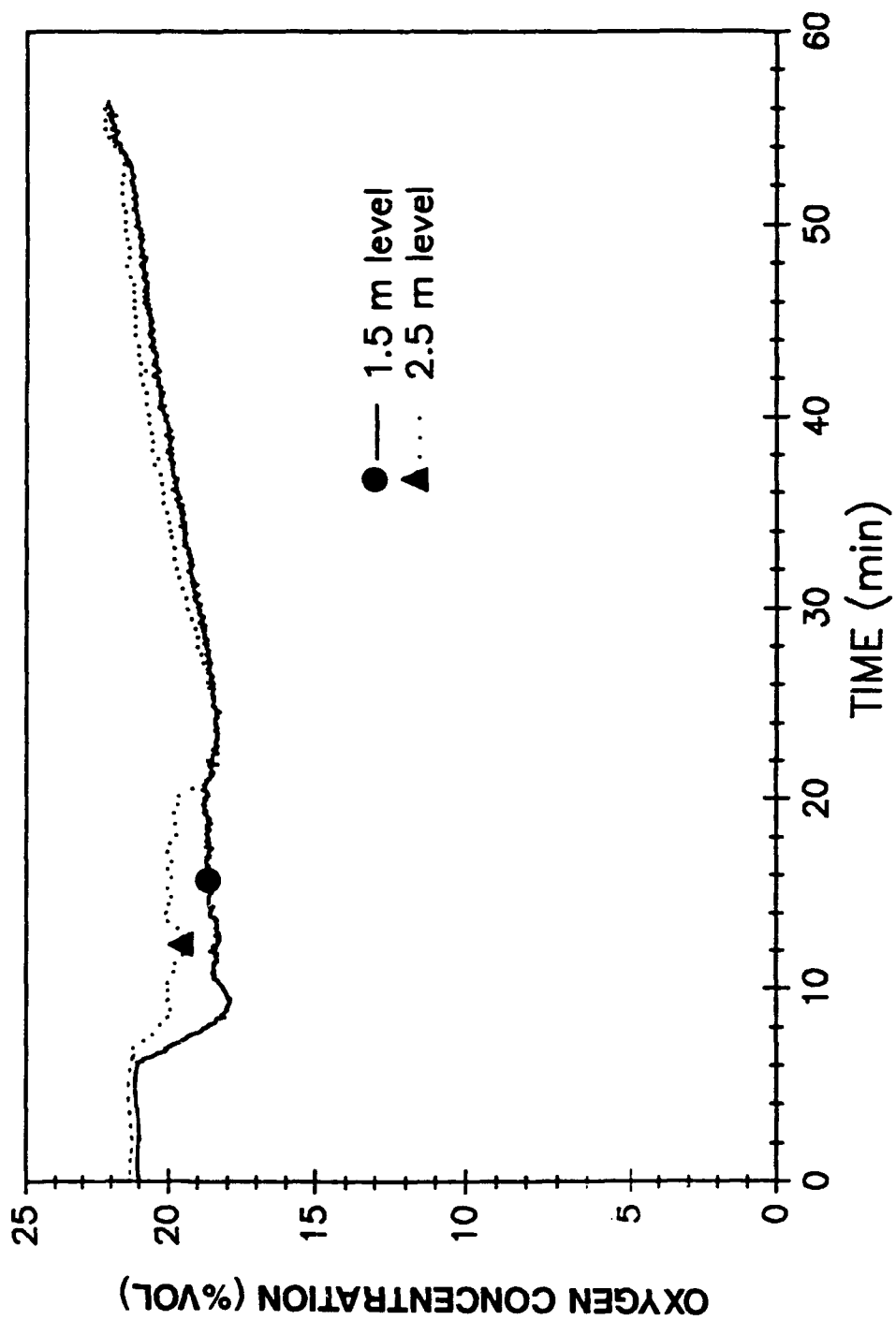


Fig. 48 - Oxygen concentrations in RICER 1 during FAN\_10  
using Red Devil 20.3 cm (8 in)

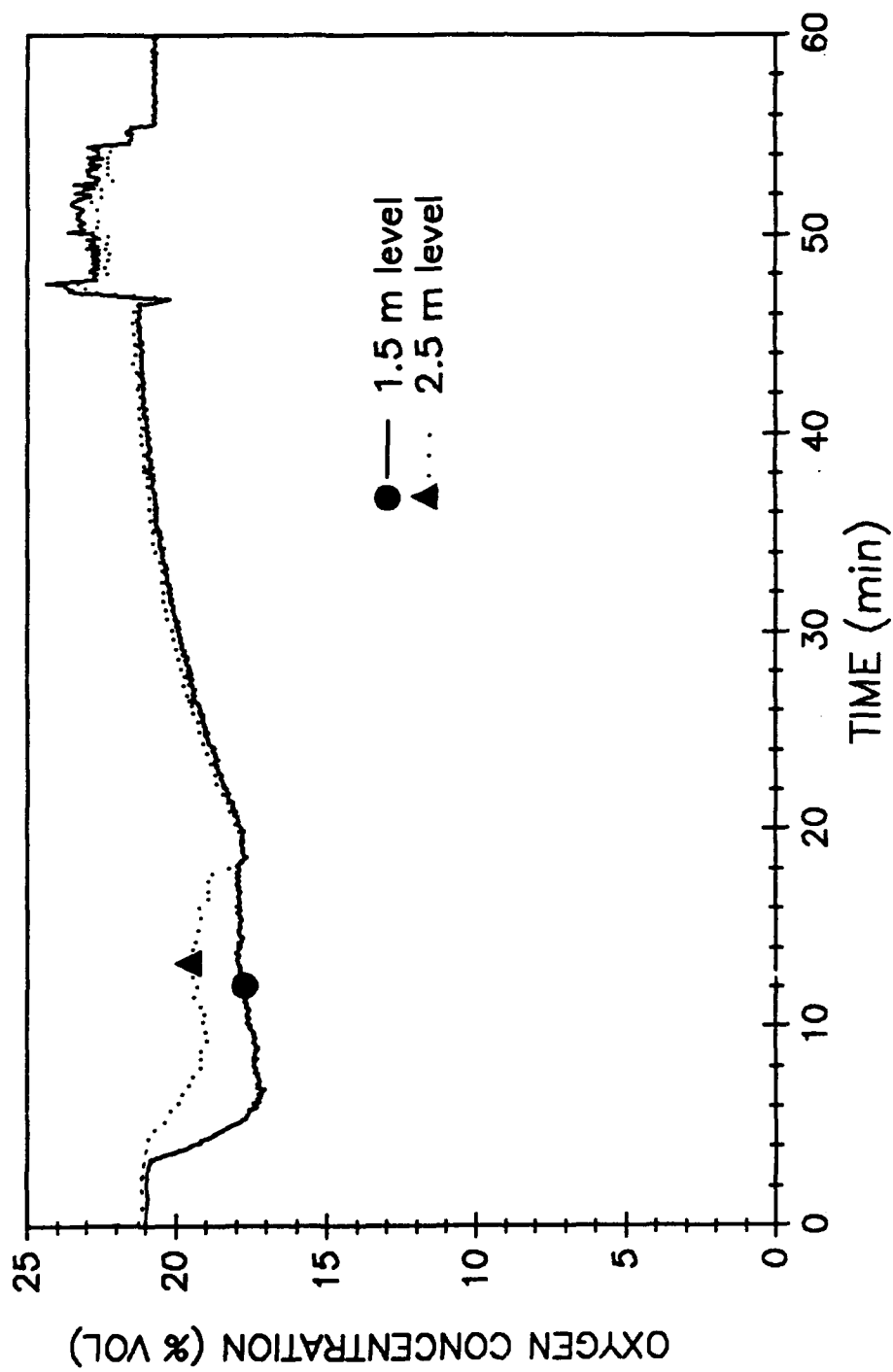


Fig. 49 - Oxygen concentrations in RICER 1 during FAN\_12  
using Red Devil 25.4 cm (10 in)

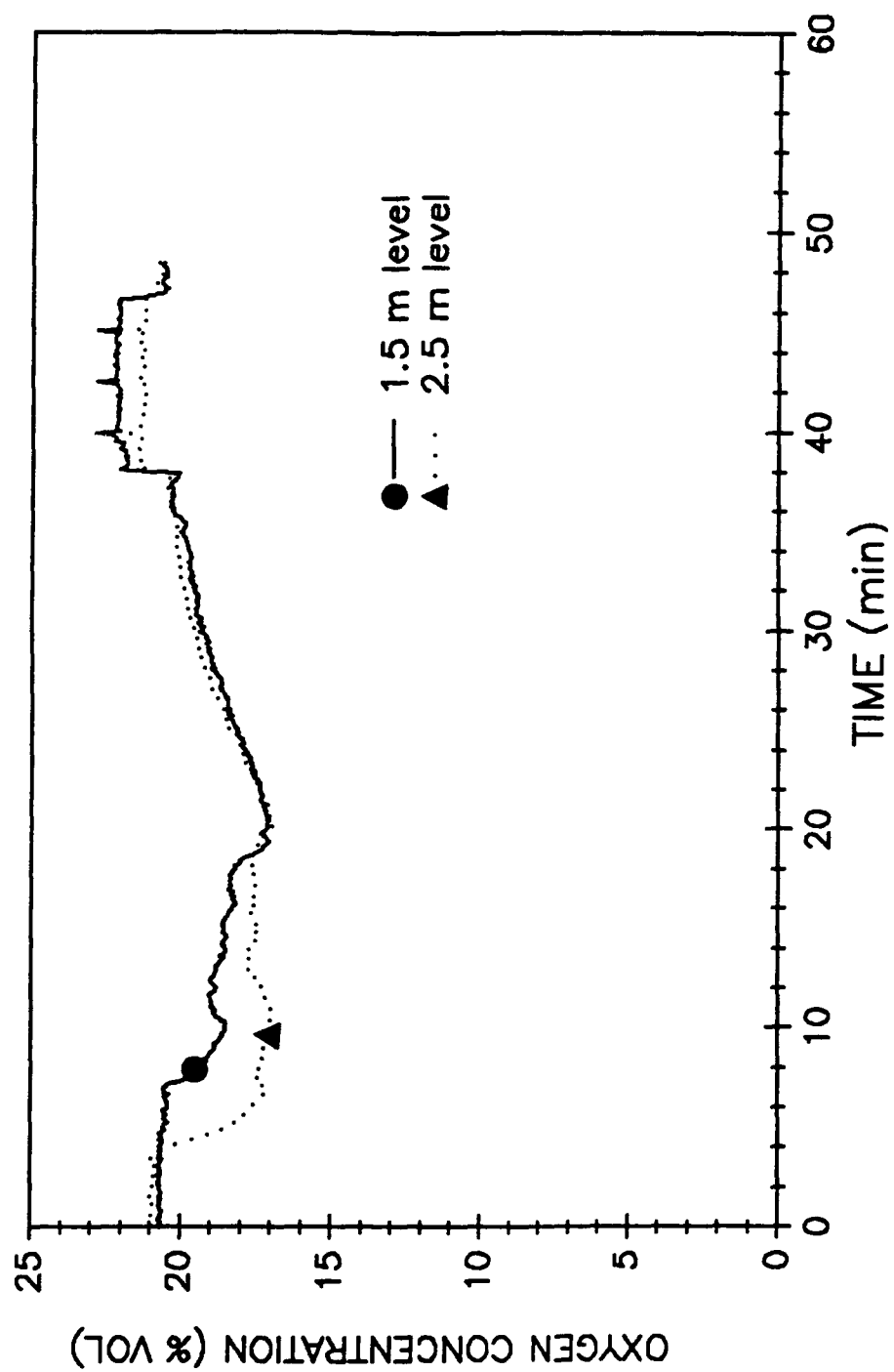


Fig. 50 - Oxygen concentrations in RICER 1 during FAN\_15  
using RAMFAN 345 kPa (50 psi)

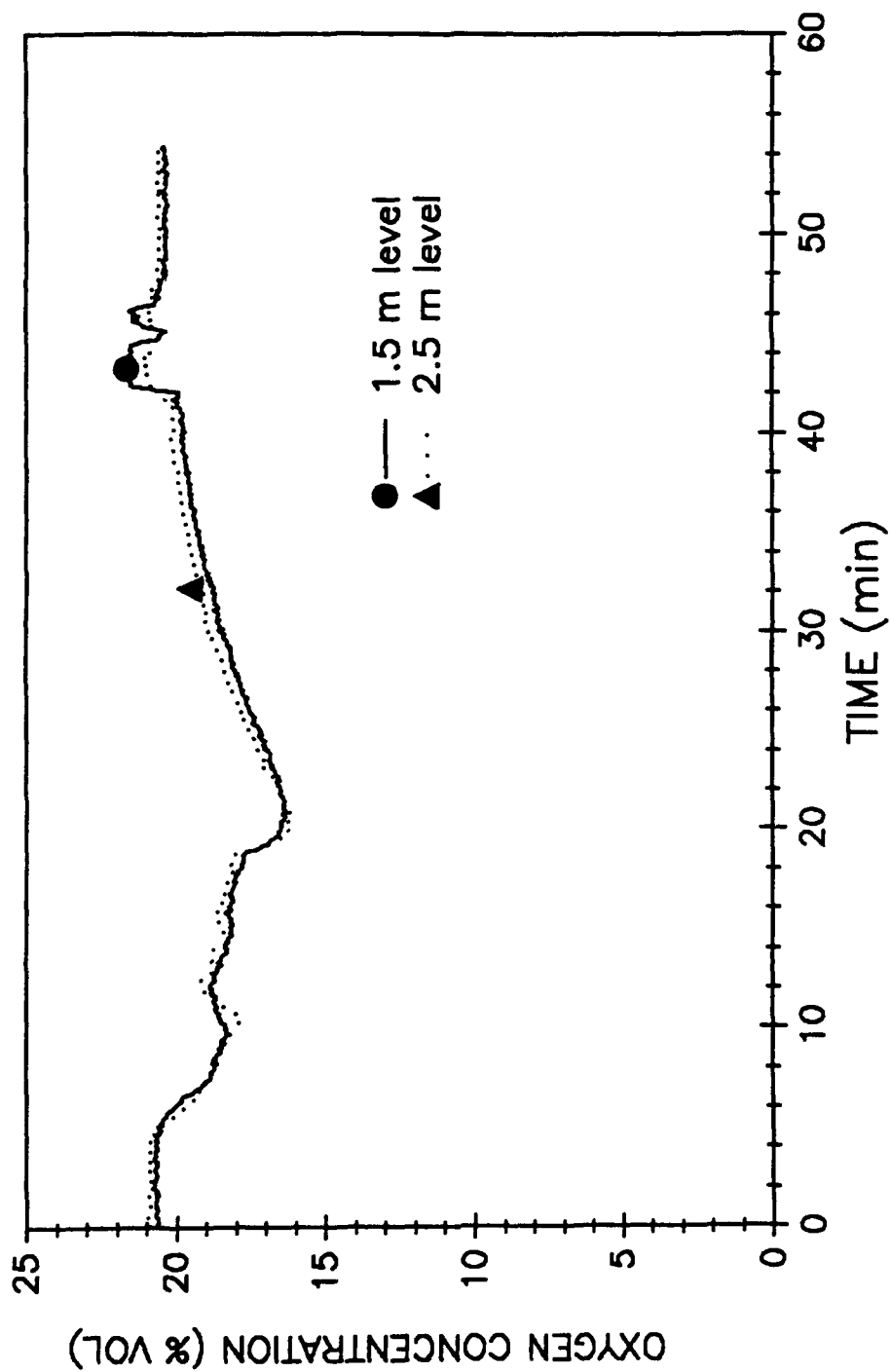


Fig. 51 - Oxygen concentrations in RICER 1 during FAN\_16  
using Red Devil 25.4 cm (10 in)

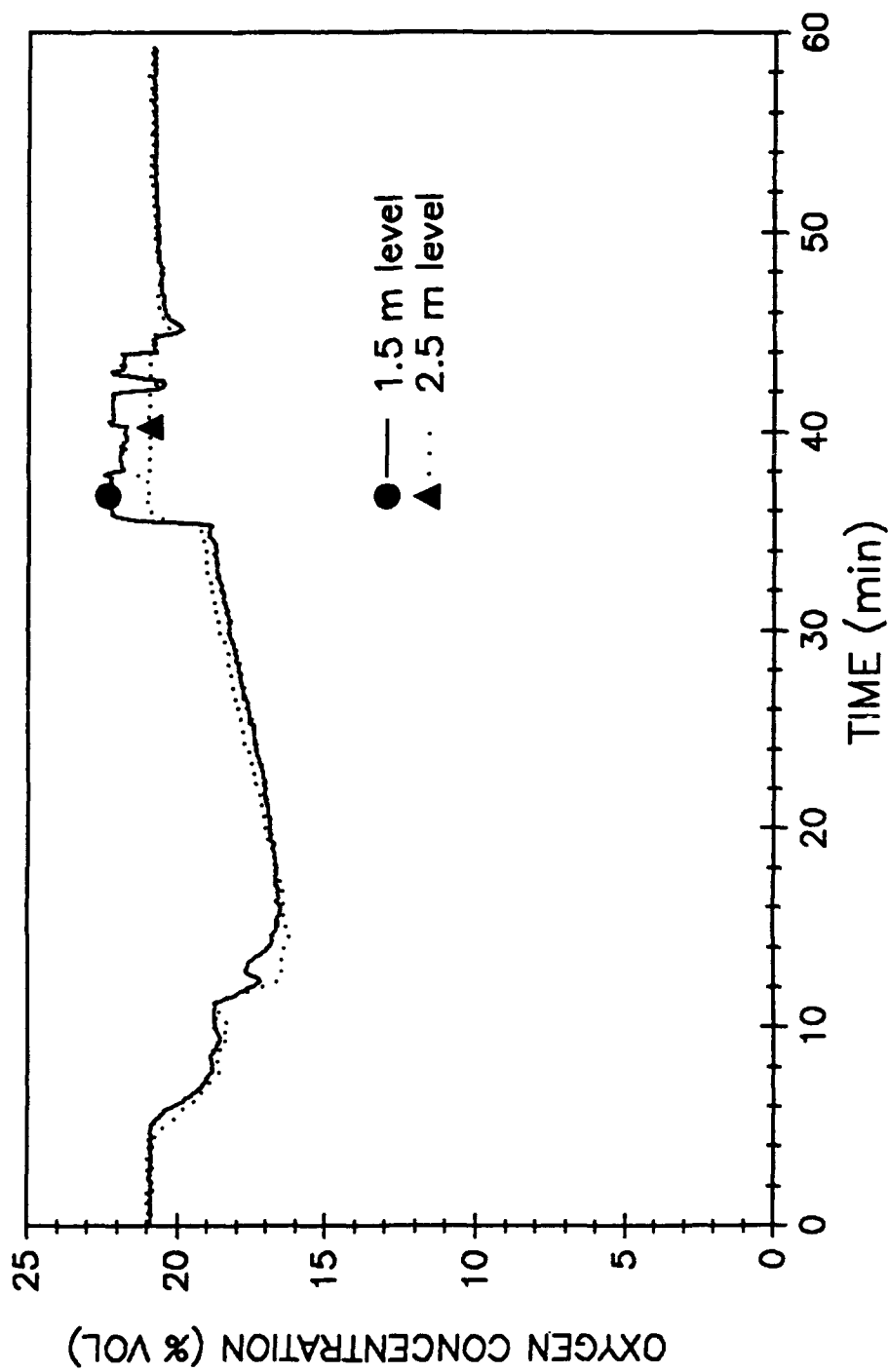


Fig. 52 - Oxygen concentrations in RICER 1 during FAN\_17  
using Red Devil 20.3 cm (8 in)



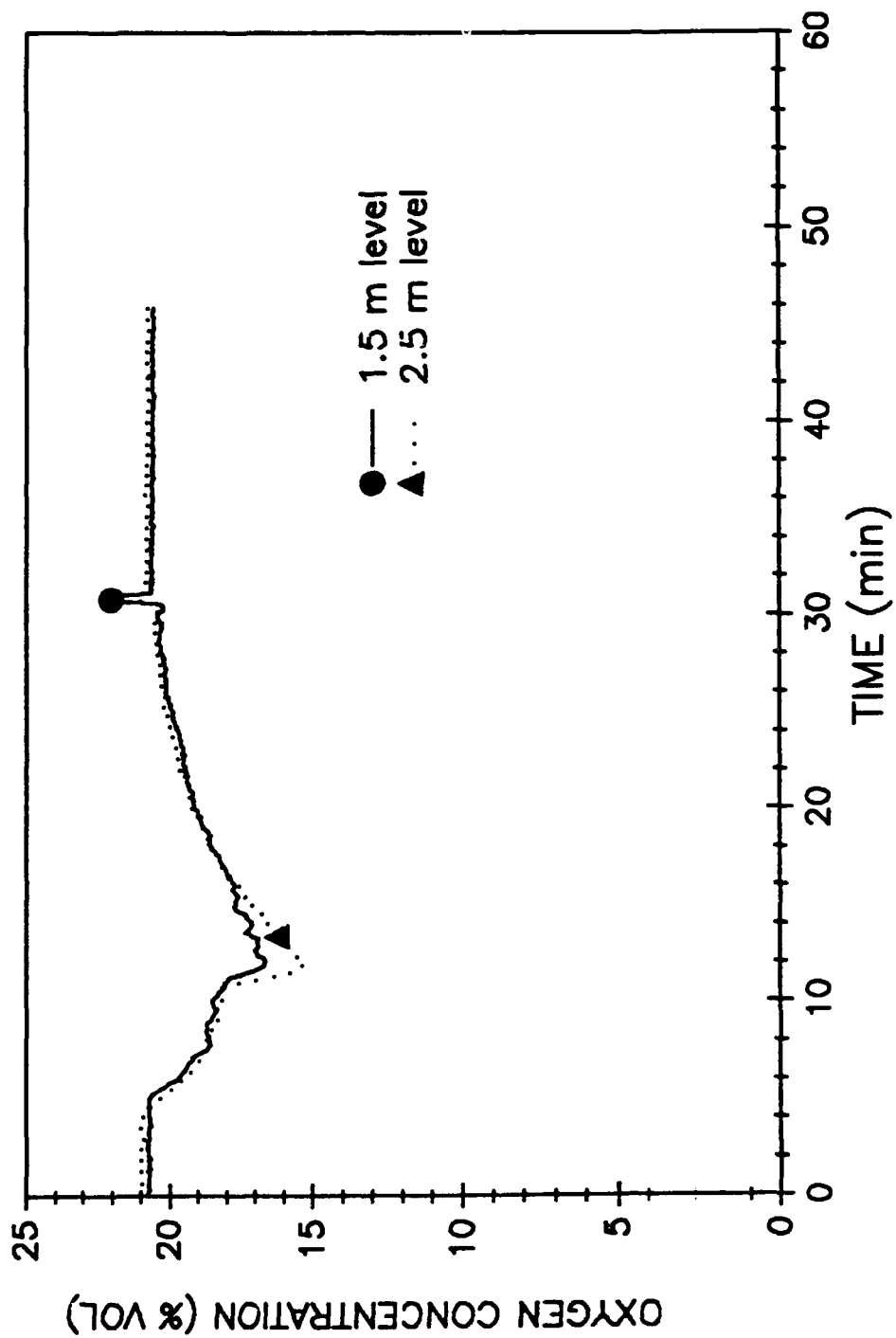


Fig. 53 - Oxygen concentrations in RICER 1 during FAN\_18  
using RAMFAN 965 kPa (145 psi)

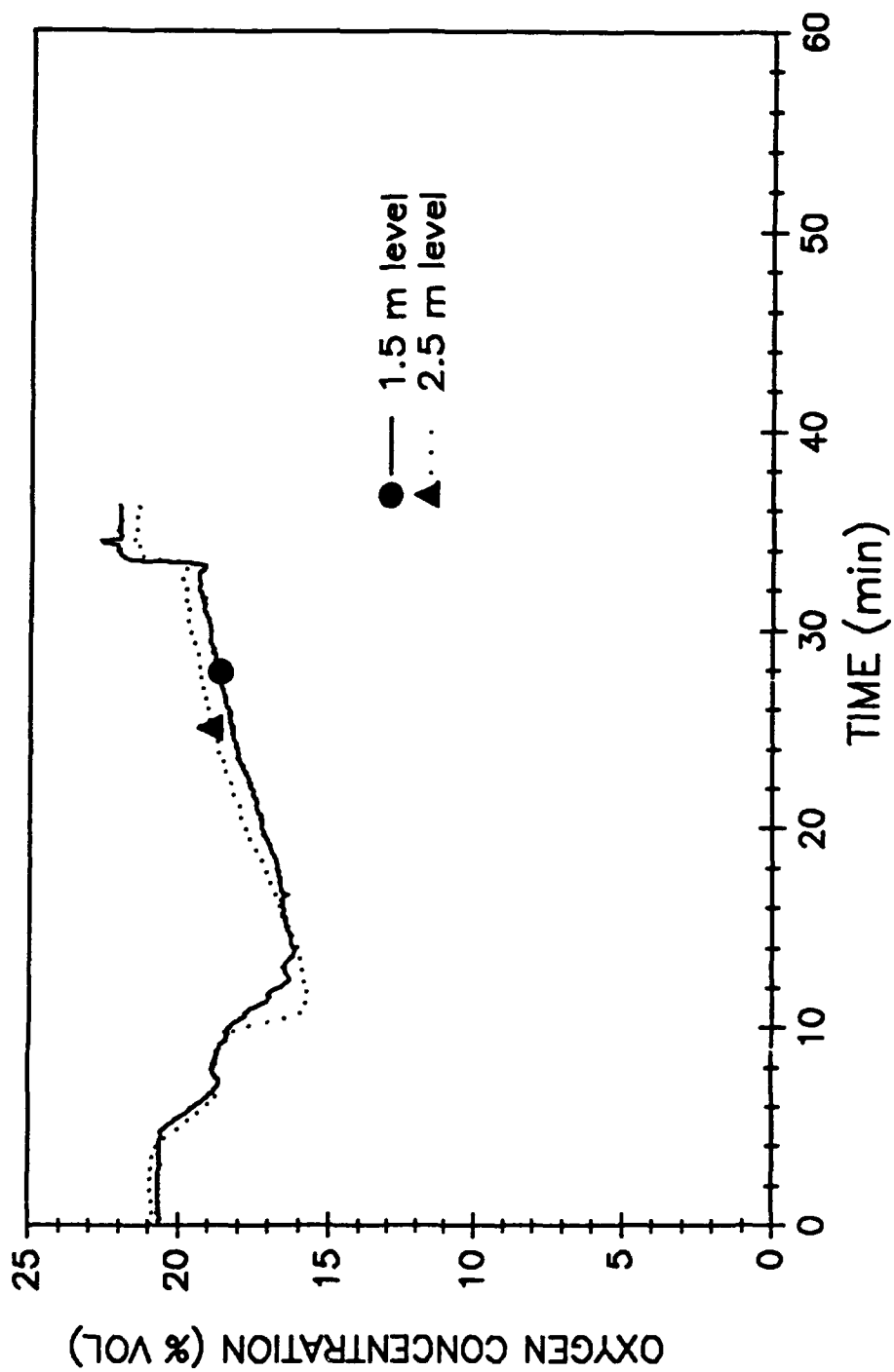


Fig. 54 - Oxygen concentrations in RICER 1 during FAN\_19  
using Red Devil 25.4 cm (10 in)

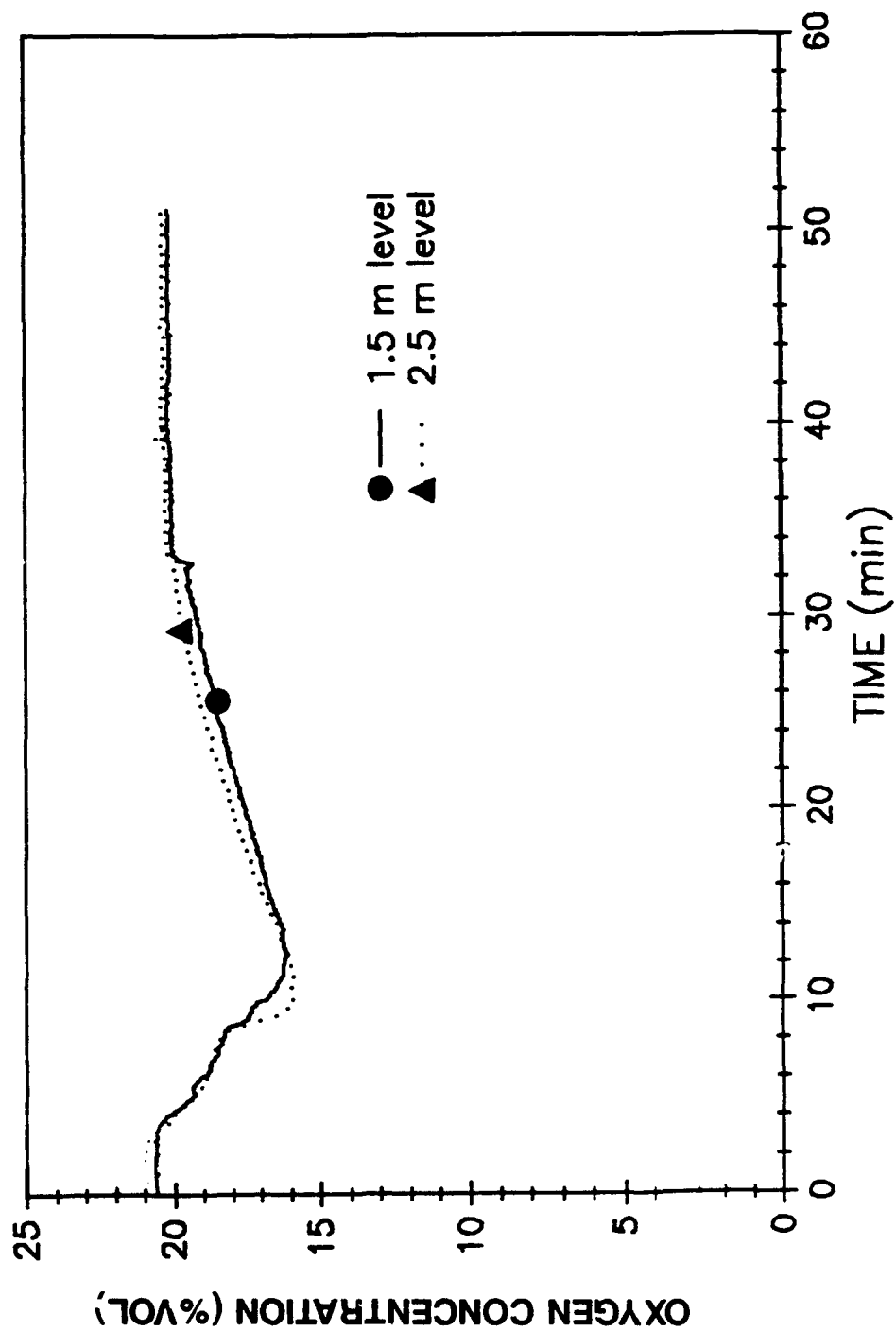


Fig. 55 - Oxygen concentrations in RICER 1 during FAN\_20  
using RAMFAN 345 kPa (50 psi)

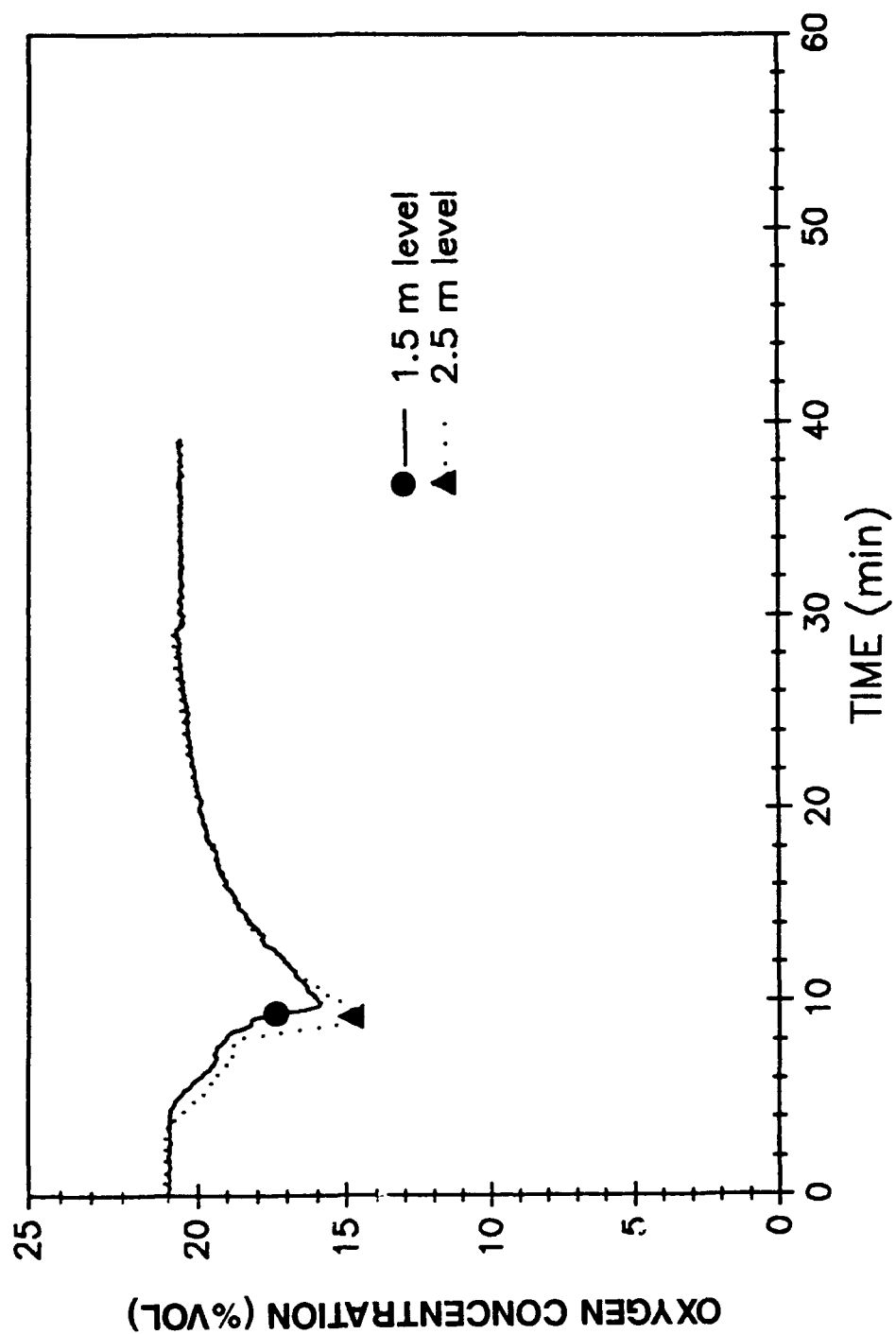


Fig. 56 - Oxygen concentrations in RICER 1 during FAN\_22  
using RAMFAN 965 kPa (145 psi)

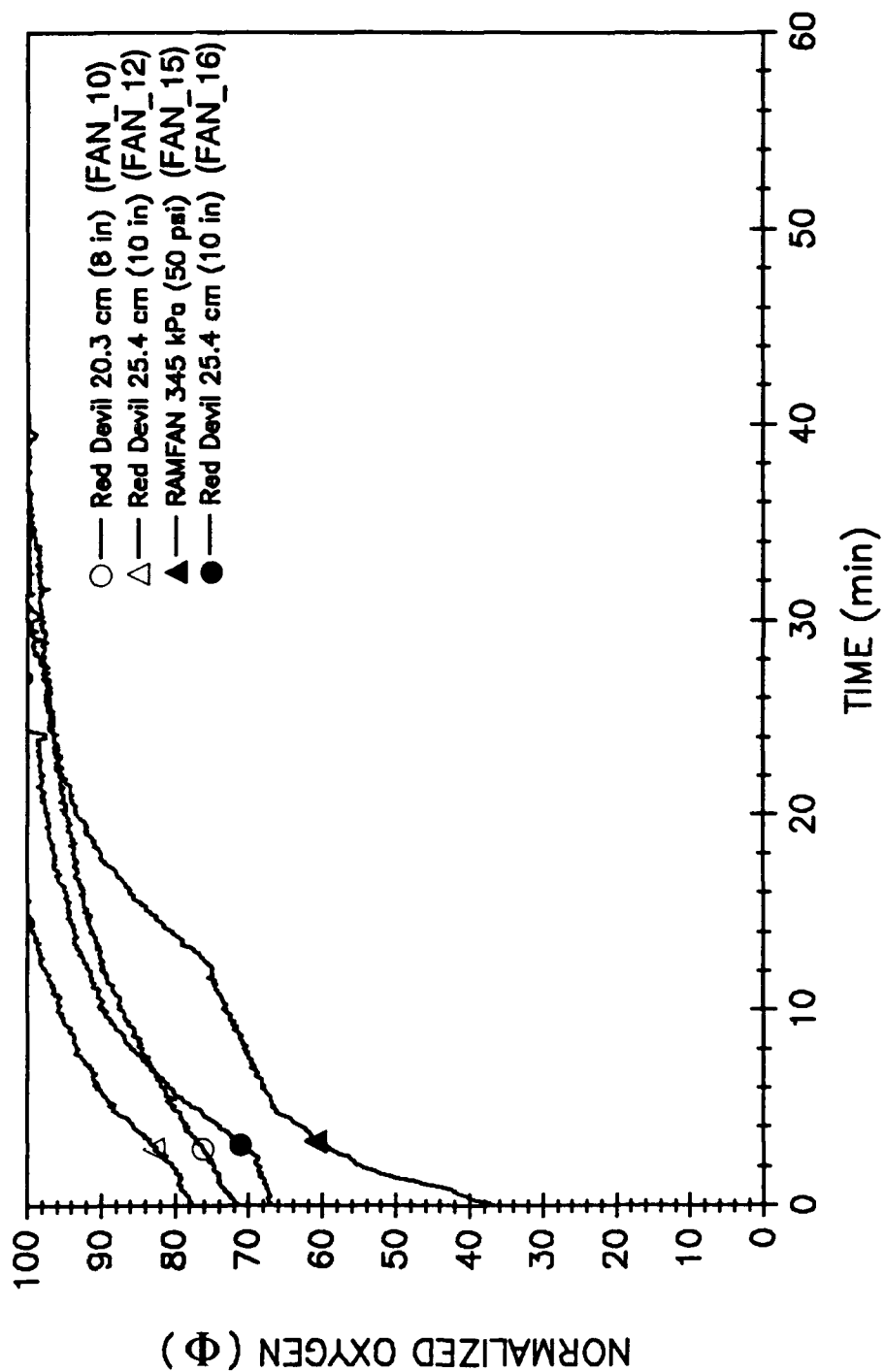


Fig. 57 - Recovery of normalized oxygen in BERTHING 1 at 1.5 m level after fan is activated

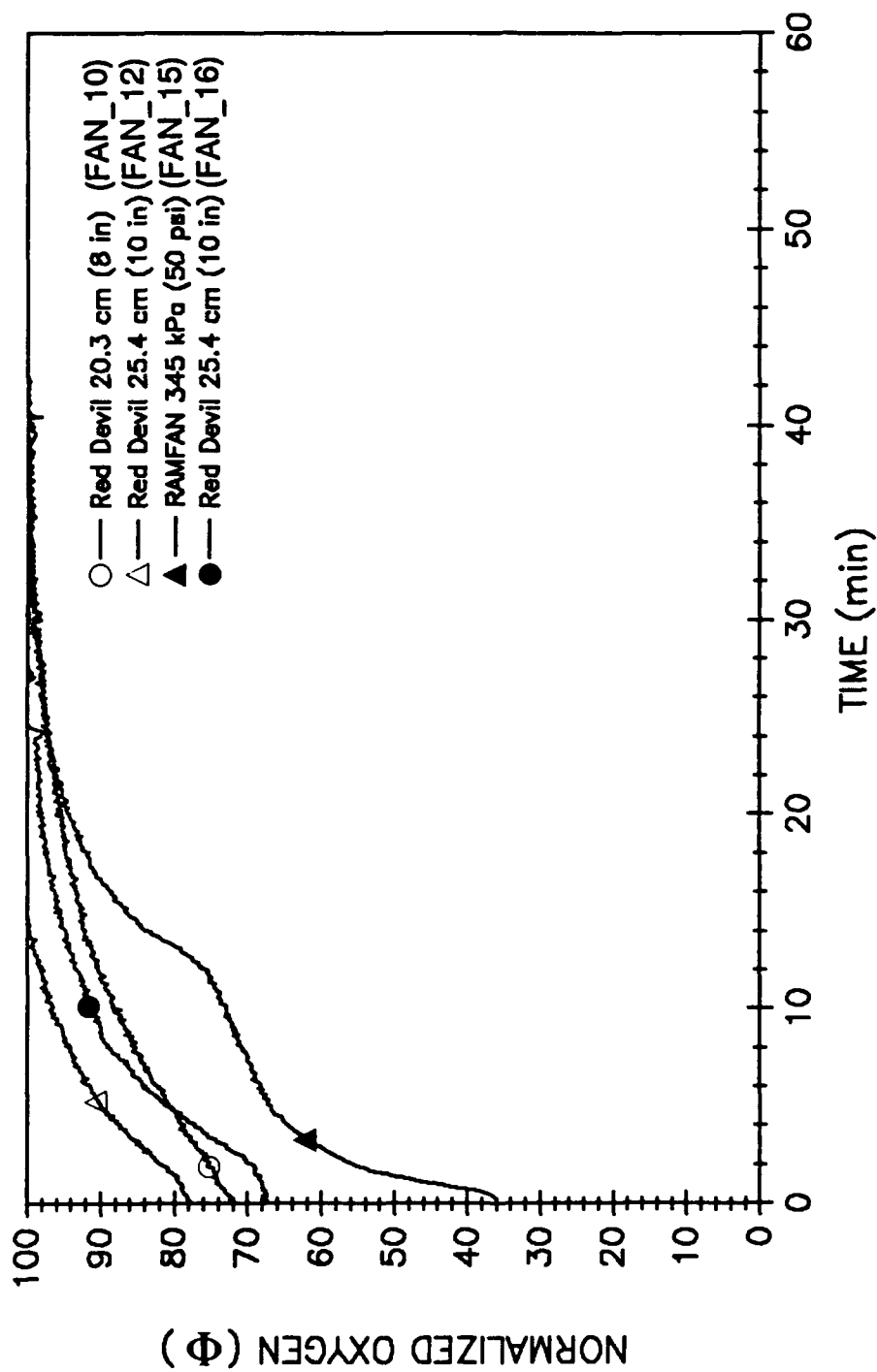


Fig. 58 - Recovery of normalized oxygen in BERTHING 1 at 2.5 m level after fan is activated

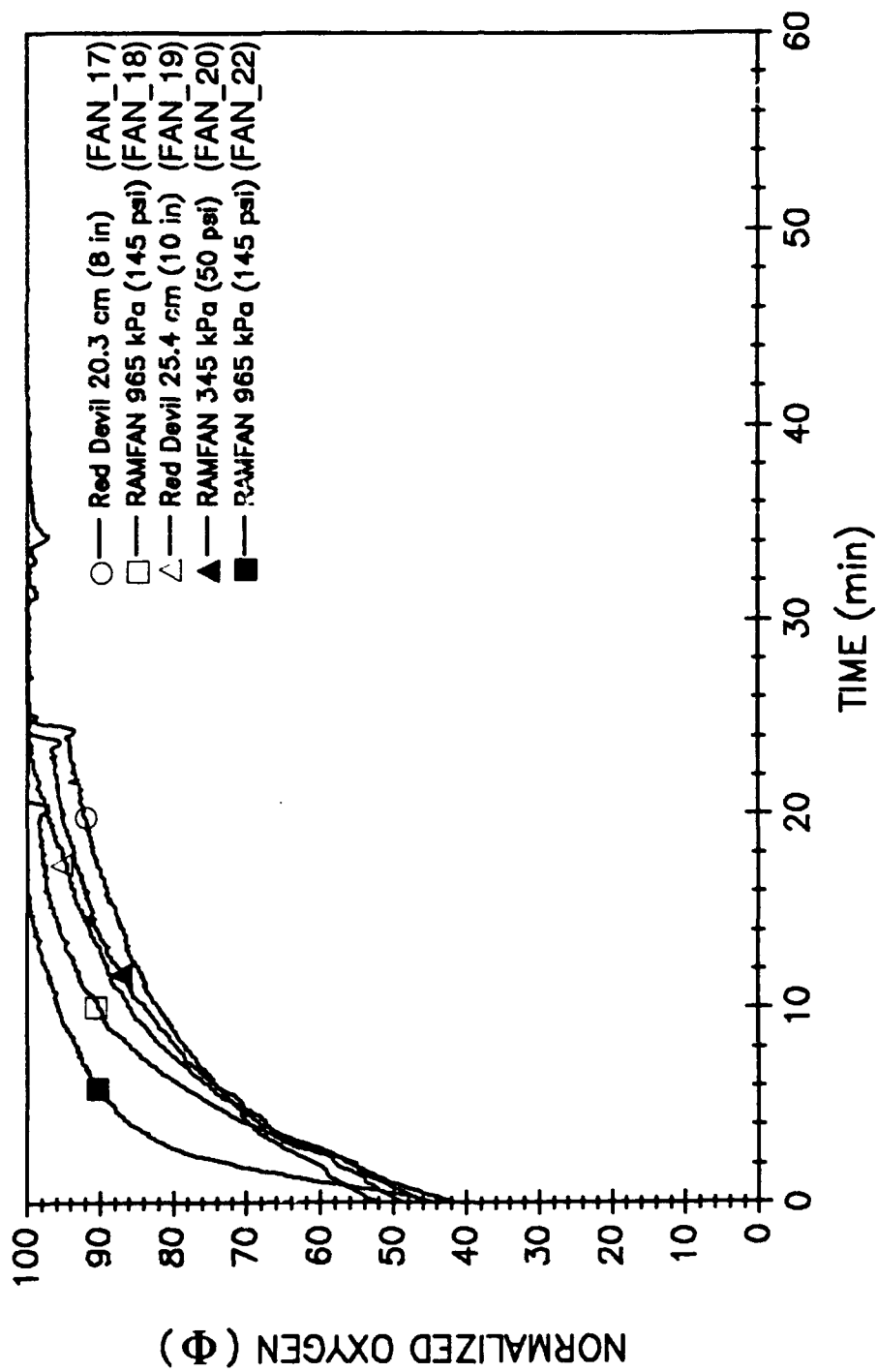


Fig. 59 - Recovery of normalized oxygen in BERTHING 1 at 1.5 m level after fan is activated

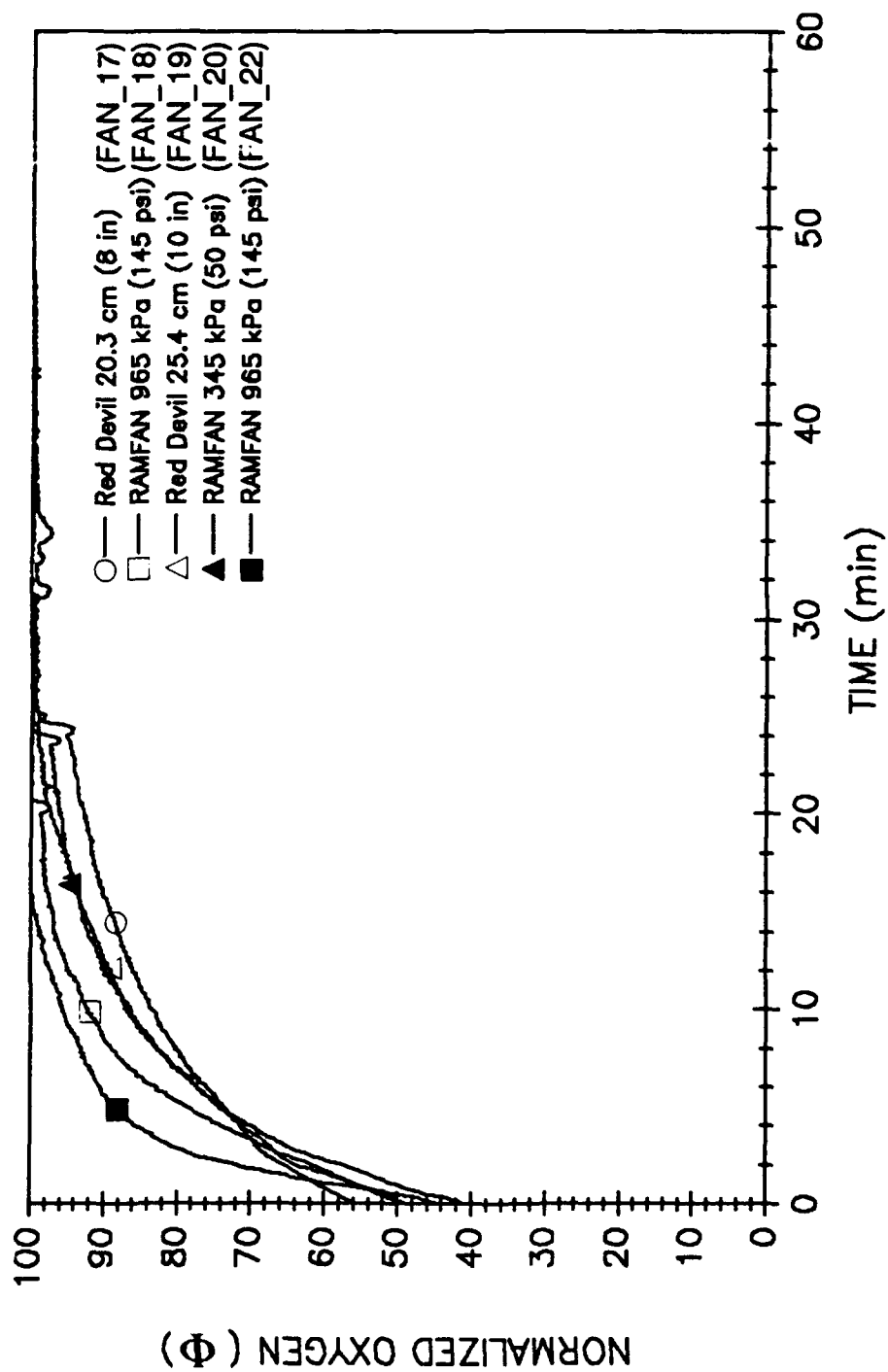


Fig. 60 - Recovery of normalized oxygen in BERTHING 1 at 2.5 m level after fan is activated



### 8.3.3 Temperature Recovery

Figures 61-69 show the temperatures in BERTHING 1 for the selected small scale tests after ignition of the heptane using either the Red Devil or the RAMFAN. Figures 70 and 71 show the temperatures in BERTHING 1 during natural venting (FAN\_39) and natural smoke settling (FAN\_40), respectively. During the natural venting test, the scuttle to RICER 1 was open during the entire test unlike the other desmoking tests where the fan was activated after the heptane fire was out.

In these tests, the desmoking fans were activated after the fire was out; therefore, cooling of the compartment had already started. To determine if the desmoking fans had any cooling effect on the compartment, the desmoking tests need to be compared to the natural smoke settling test. Figure 72 compares the average temperature of a WMF test to natural smoke settling. No cooling advantages can be seen with the desmoking fan from this graph. Also to be noted from this figure is the natural venting plot. Since the scuttle was open during the entire test, this drew the heat from BERTHING 2; thus, the temperatures in BERTHING 1 were higher. Natural venting will be discussed in more detail in the next section.

### 8.3.4 Natural Venting

A natural venting test was conducted where the scuttle to RICER 1 was open during the entire test. From Figures 70 and 71, in comparing natural venting and natural smoke settling, the temperature recovery of natural venting was not as quick as the natural smoke settling. The percent transmittance decreased before it improved, and the recovery time was longer as compared to the other tests (Fig. 73). Also, after the fire was out, temperatures remained 20-30 degrees higher for approximately 12 minutes than the other desmoking fan tests (Figs. 70 and 72).

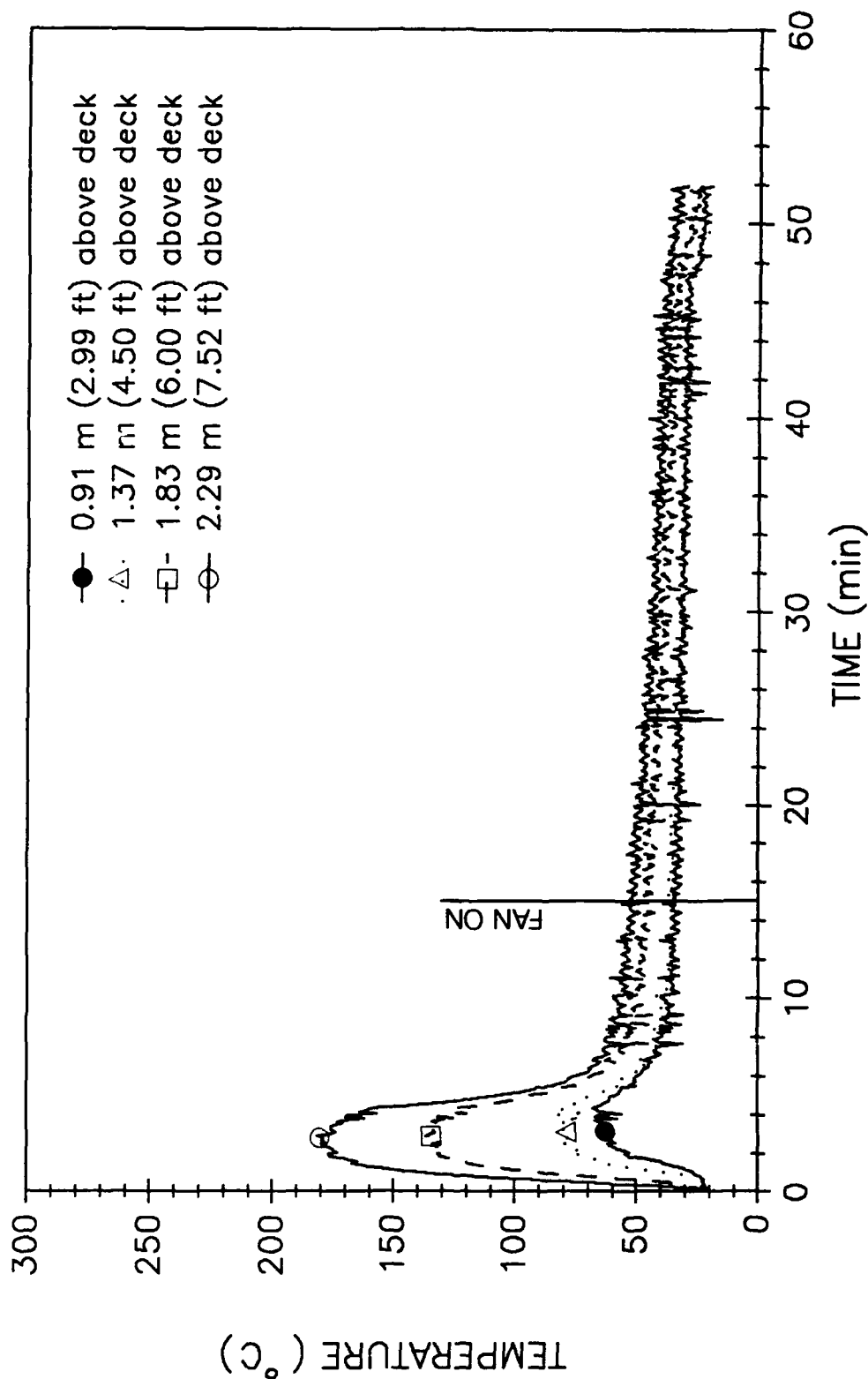


Fig. 61 - Temperature in BERTHING 1 (3-79-2) during FAN\_10 using Red Devil 20.3 cm (8 in) duct

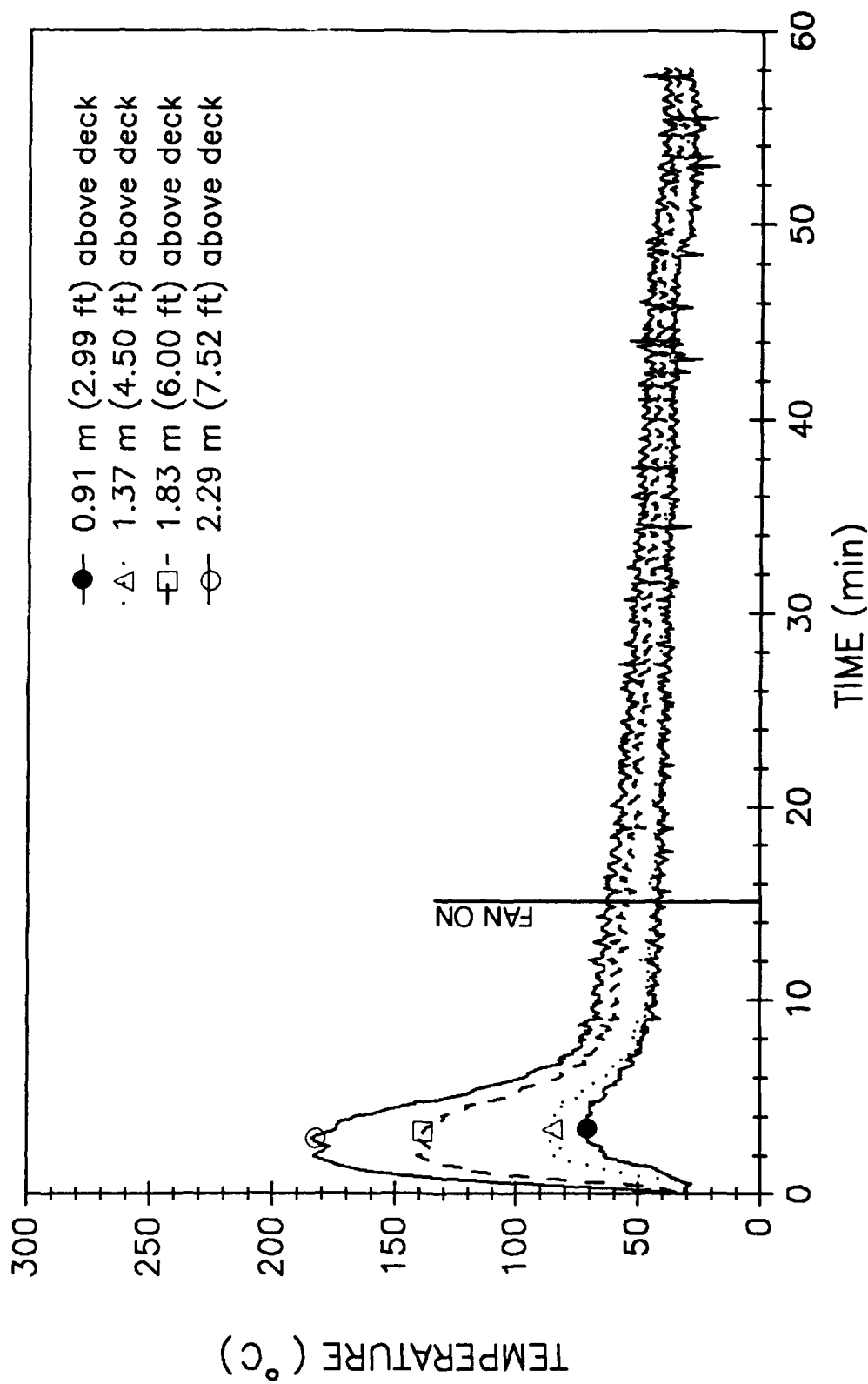


Fig. 62 - Temperature in BERTHING 1 (3-79-2) during FAN\_12  
using Red Devil 25.4 cm (10 in) duct

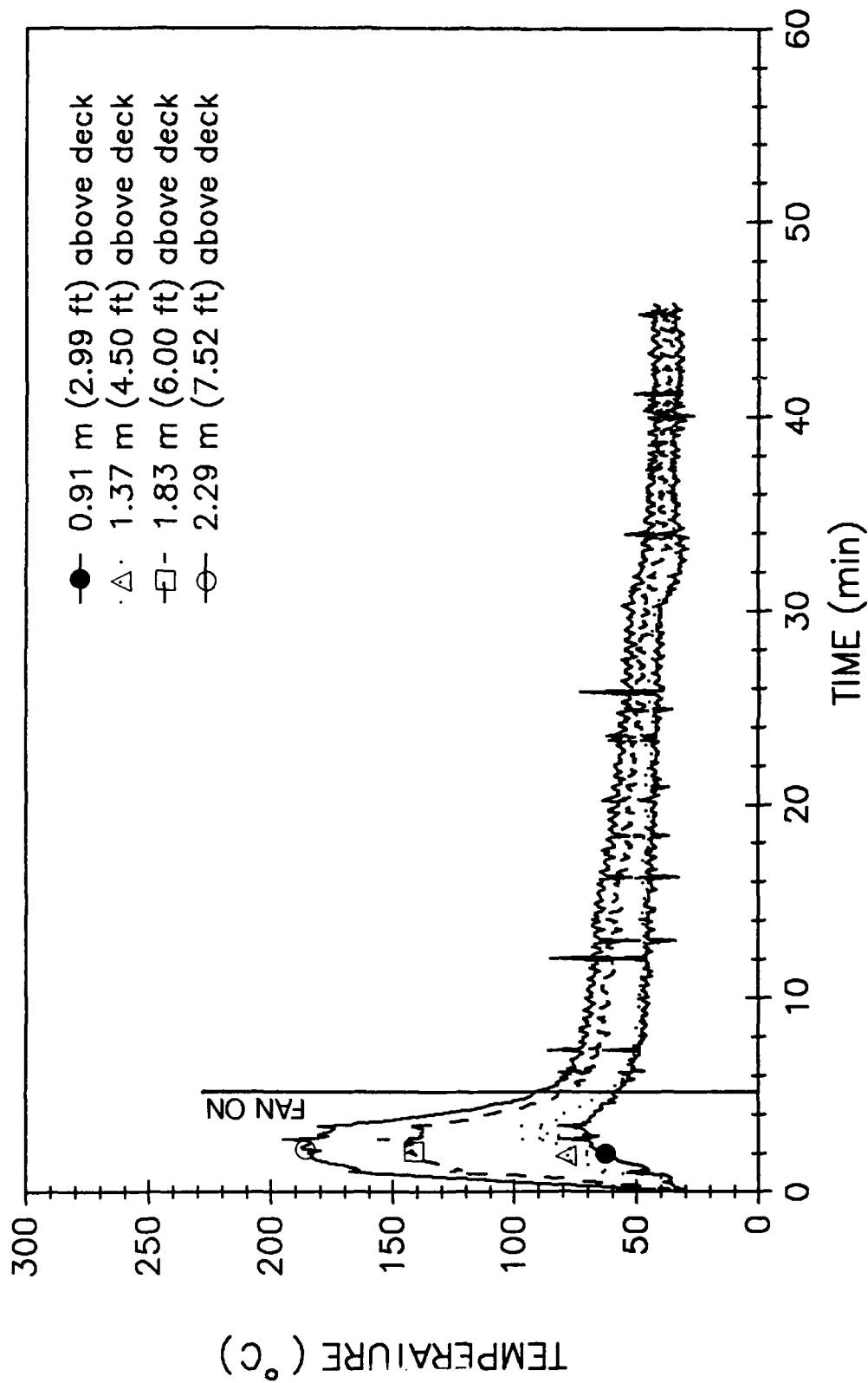


Fig. 63 - Temperature in BERTHING 1 (3-79-2) during FAN\_15 using RAMFAN 345 kPa (50 psi)

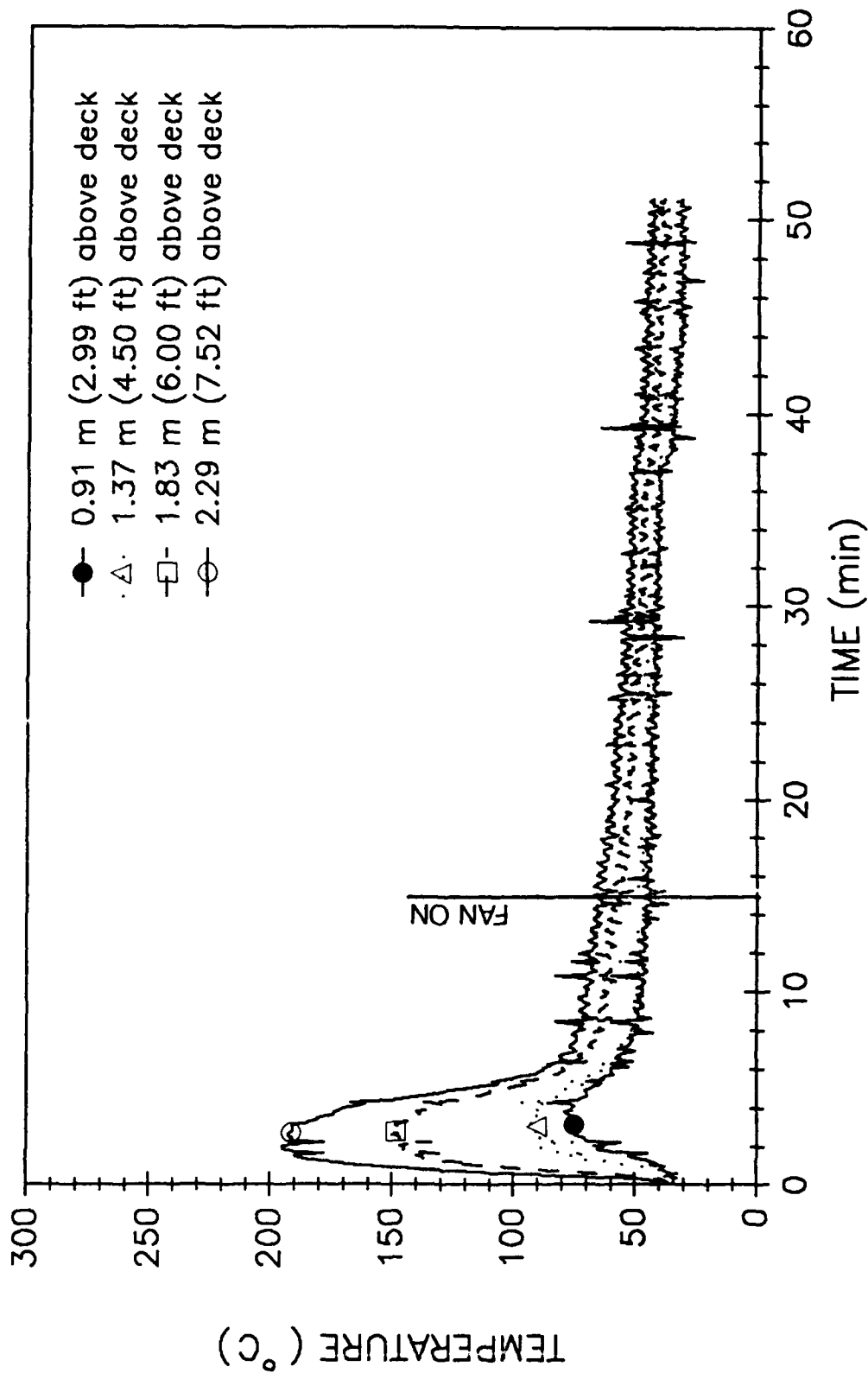


Fig. 64 - Temperature in BERTHING 1 (3-79-2) during FAN\_16  
using Red Devil 25.4 cm (10 in) duct

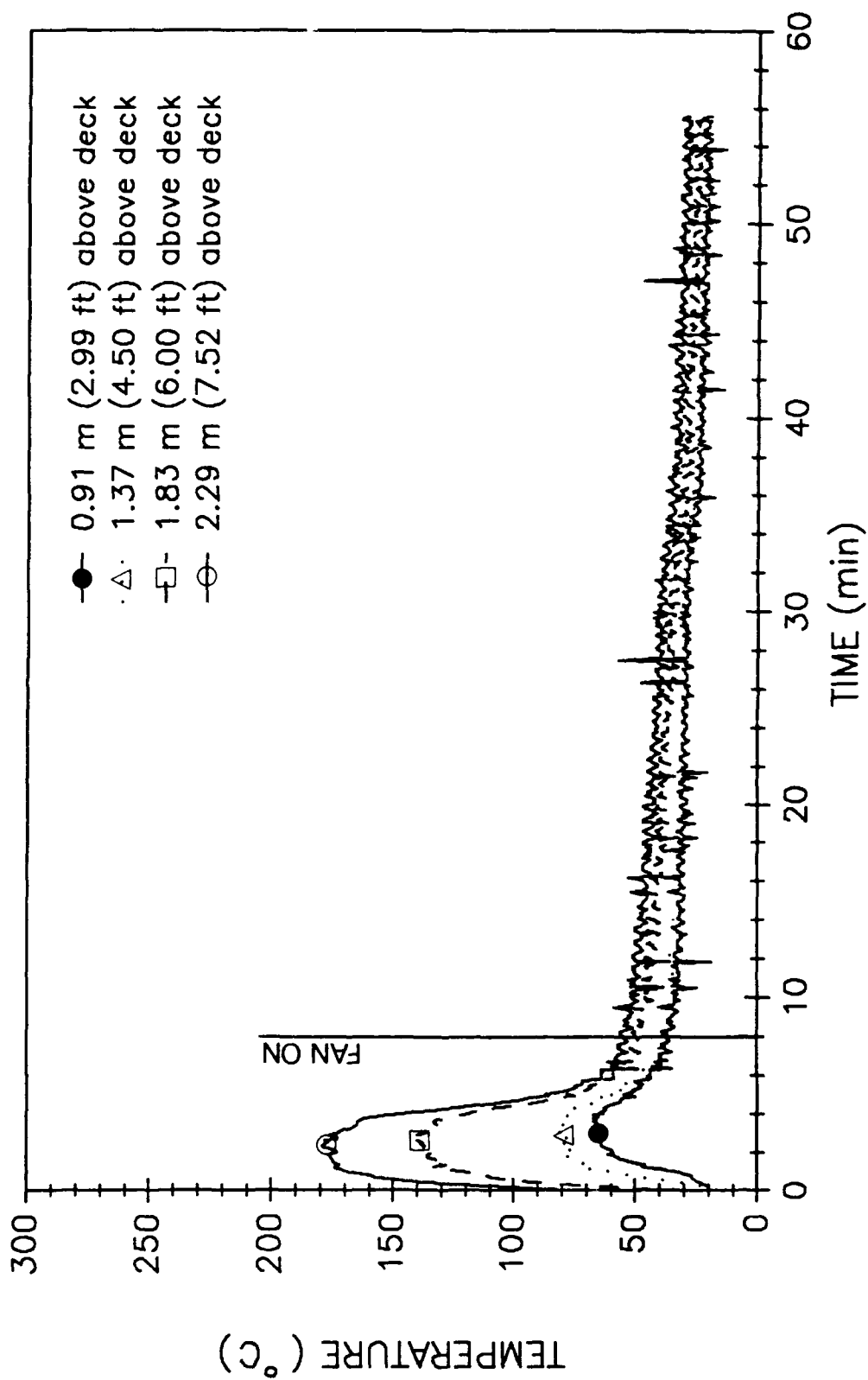


Fig. 65 - Temperature in BERTHING 1 (3-79-2) during FAN\_17 using Red Devil 20.3 cm (8 in) duct

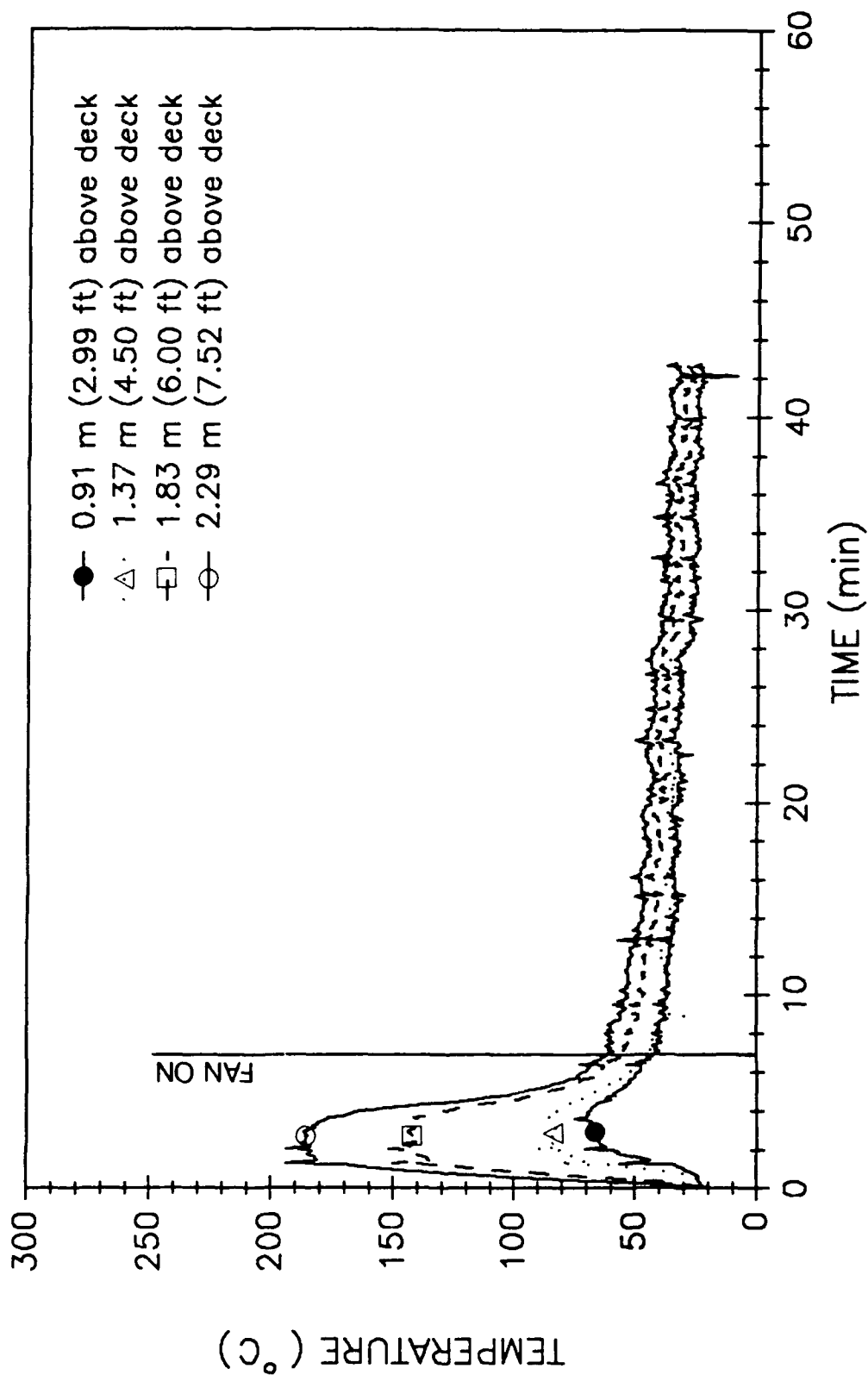


Fig. 66 - Temperature in BERTHING 1 (3-79-2) during FAN\_18  
using RAMFAN 965 kPa (140 psi)

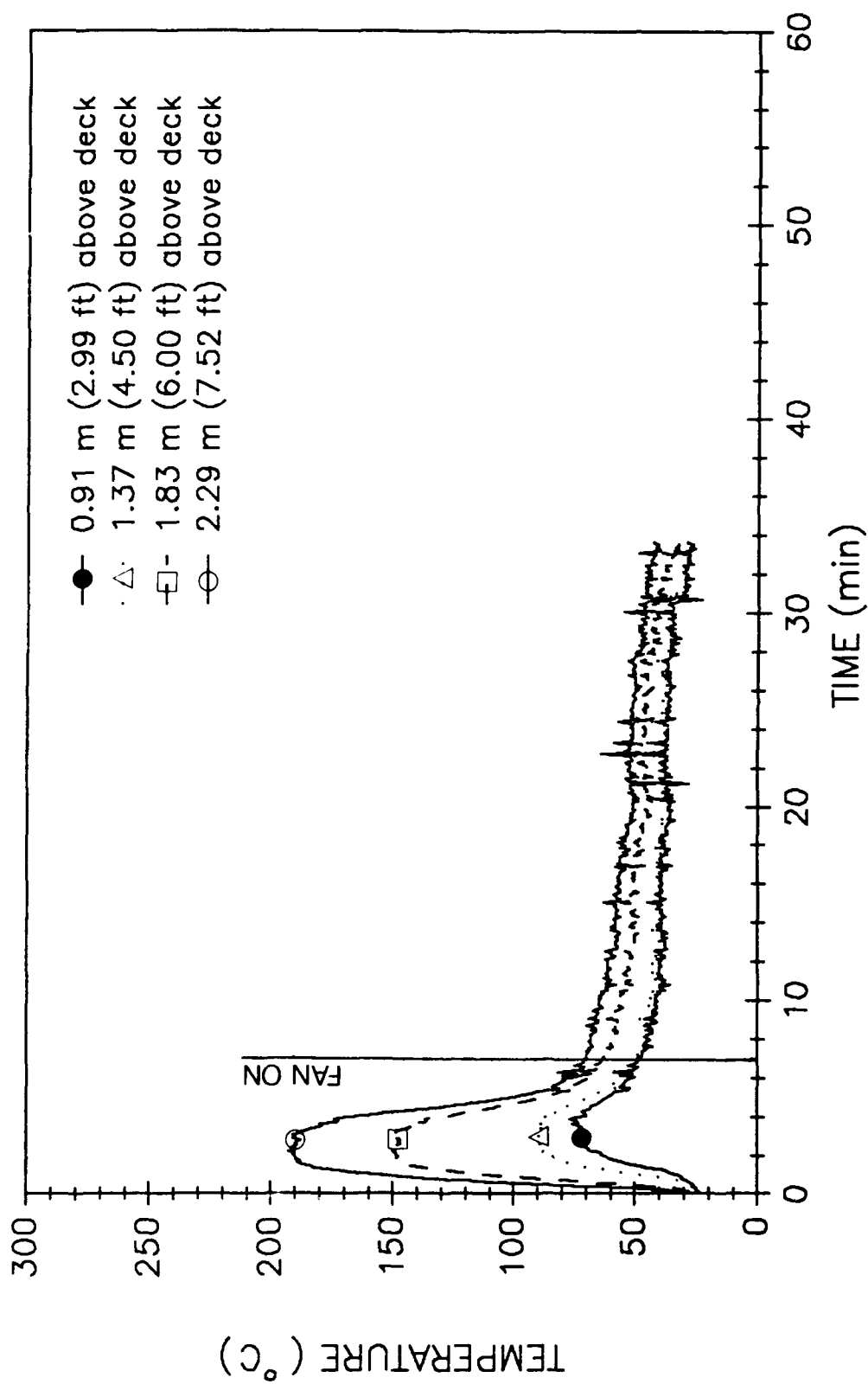


Fig. 67 - Temperature in BERTHING 1 (3-79-2) during FAN\_19  
using Red Devil 25.4 cm (10 in) duct



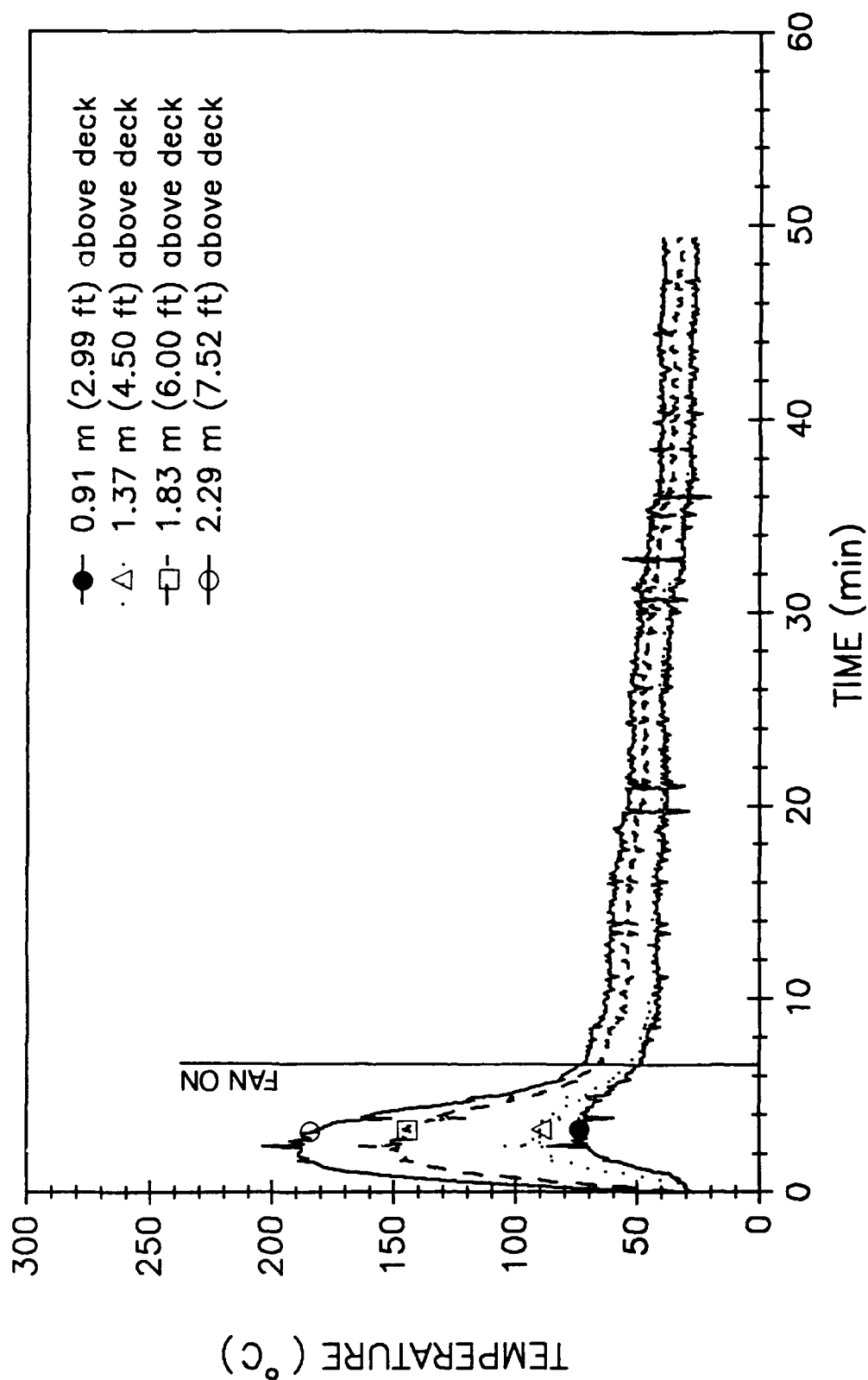


Fig. 68 - Temperature in BERTHING 1 (3-79-2) during FAN\_20  
using RAMFAN 345 kPa (50 psi)

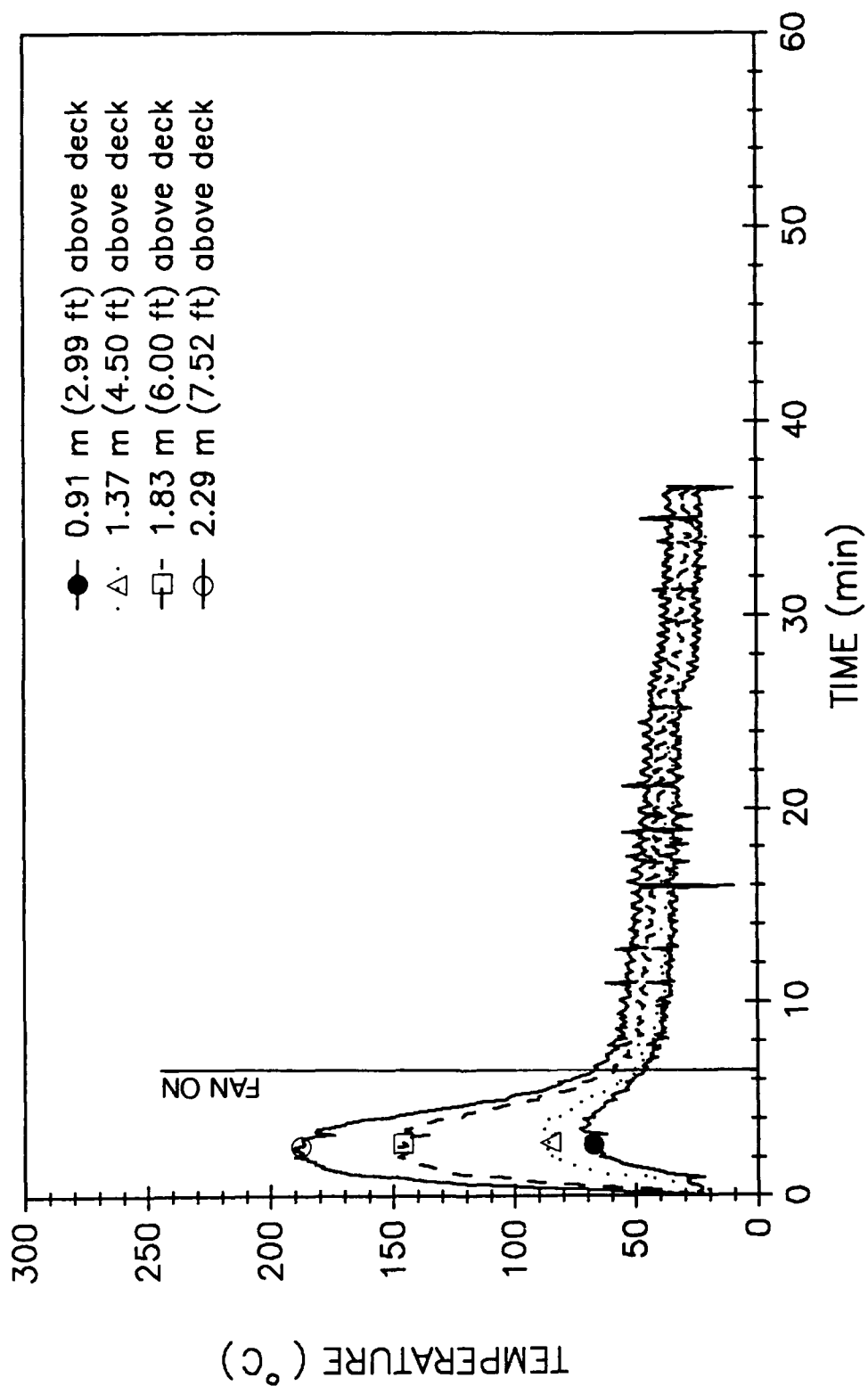


Fig. 69 - Temperature in BERTHING 1 (3-79-2) during FAN\_22 using RAMFAN 1000 kPa (145 psi)

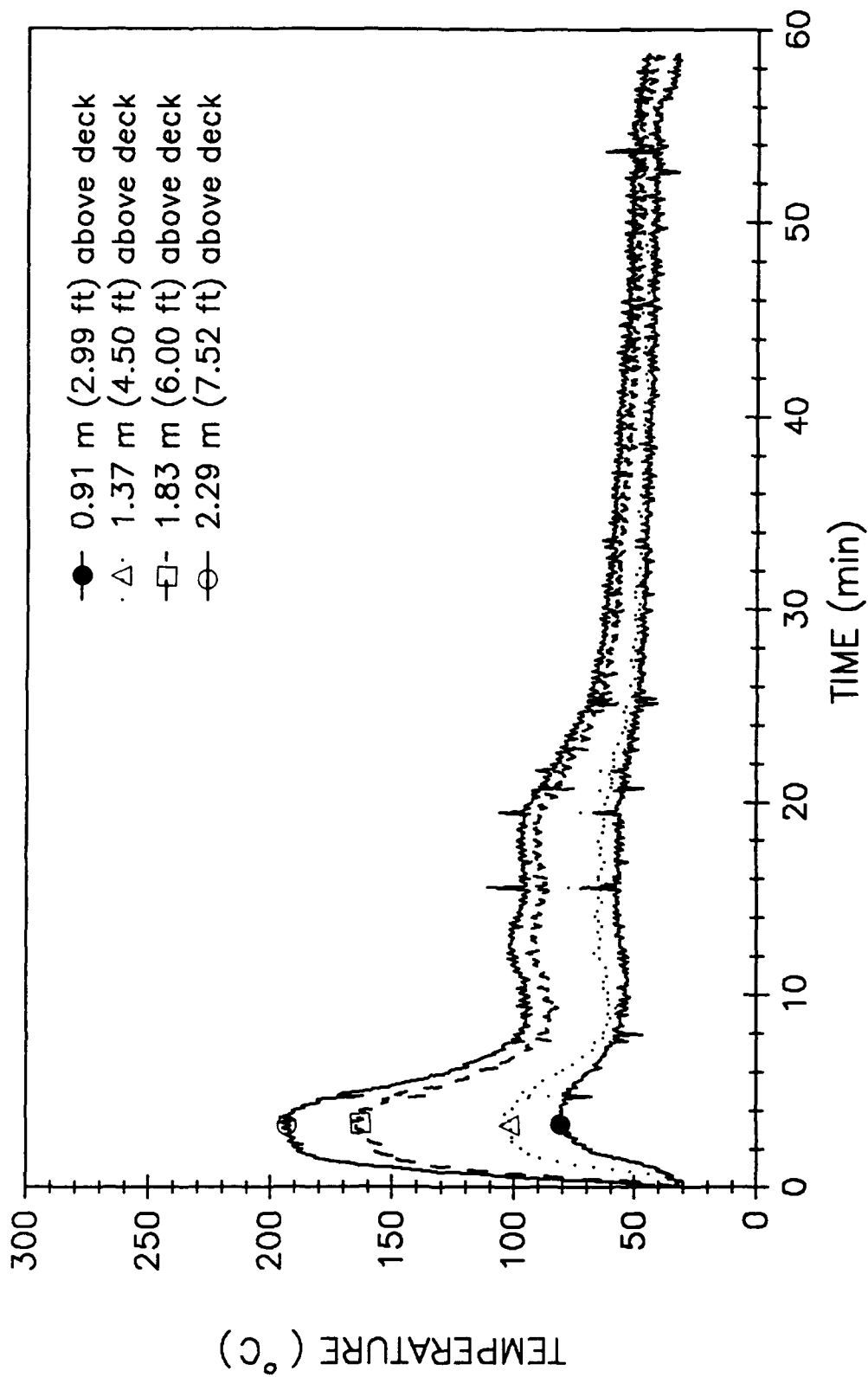


Fig. 70 - Temperature in BERTHING 1 (3-79-2) during FAN\_39 using natural venting

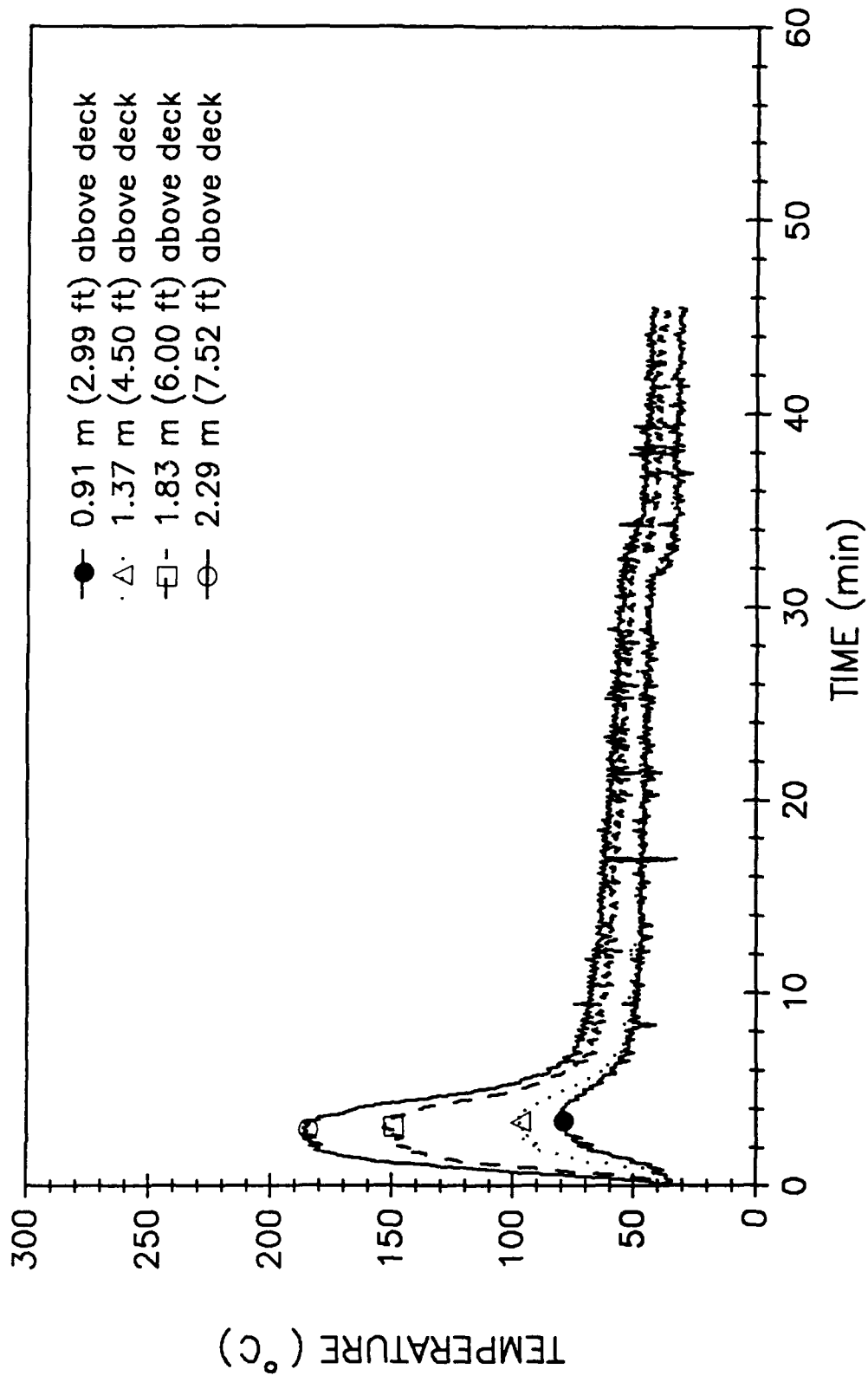


Fig. 71 - Temperature in BERTHING 1 (3-79-2) during FAN\_40 using natural smoke settling

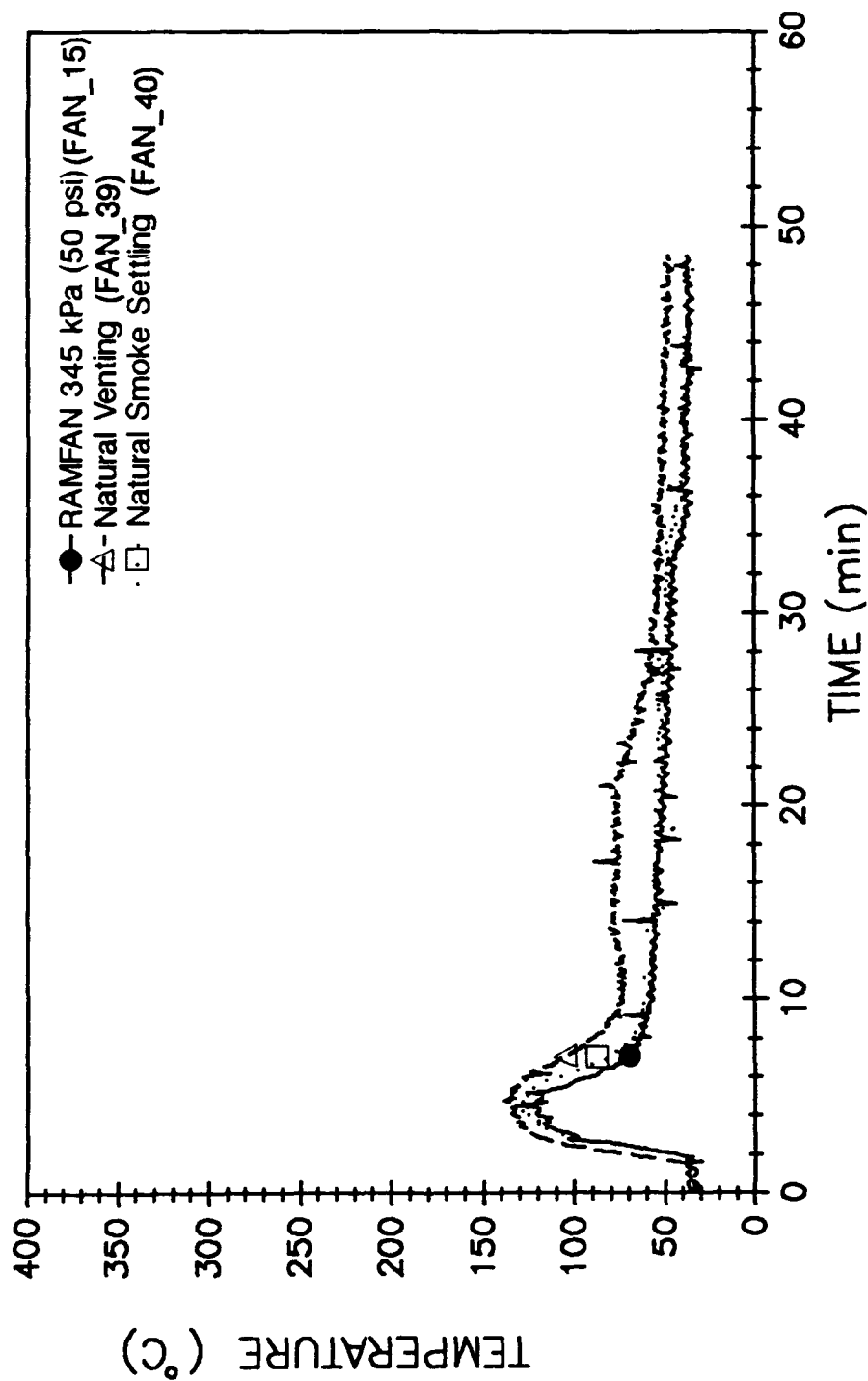


Fig. 72 - Average temperature in BERTHING 1 (3-79-2)

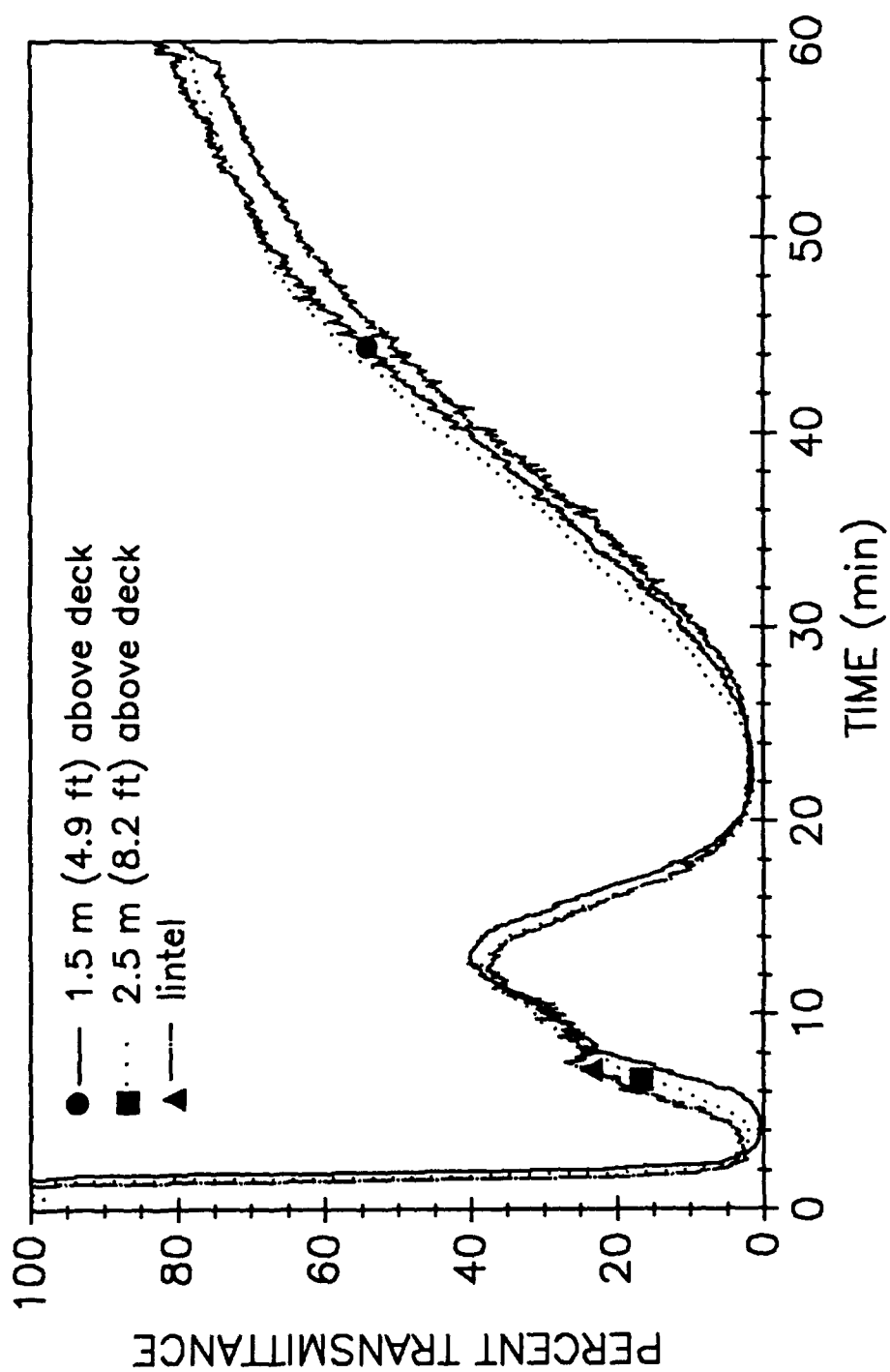


Fig. 73 - Percent transmittance in BERTHING 1 during FAN\_39 using natural venting

### 8.3.5 Fan Installation

The time to install the fans during the manned tests did not greatly vary. The time to install the water motor fan ranged from 5.5-7 minutes, an average of 6.7 minutes. The time required to install the Red Devil fan ranged from 7-9 minutes, averaging 7.8 minutes (Table 6). There was no significant difference in setup times between the 20.3 cm (8 in.) and the 25.4 cm (10 in.) ducts. These times may be impacted by the accessibility of power either electric or water. In these tests, there was ready access to both power sources. Supply ducting and smoke curtains were pre-staged; therefore, the setup time for the supply duct smoke curtains were not a variable. Overboard discharge of water was also readily available. These test-specific factors favorably affected the overall setup times. Given ready access to a power source, the rigging times of the Red Devil and RAMFAN were judged to be equivalent. The extra time required to rig water hoses for the RAMFAN appears to be offset by the more difficult handling associated with the heavier Red Devil blower.

Table 6. Time to Install Desmoking Fans of Manned Tests

<u>Fan</u>	<u>Test</u>	<u>Time to Install Fan (min)</u>
RAMFAN	FAN_18	7.3
	FAN_20	7.5
	FAN_21	6.5
	FAN_22	5.4
	FAN_24	6.1
	FAN_28	<u>7.3</u>
Average Time to Install		<u>6.7</u>
Red Devil using 25.4 cm (10 in.) duct	19	6.8
	25	<u>8.7</u>
Average Time to Install		<u>7.8</u>
Red Devil using 20.3 cm (8 in.) duct	17	7.8

### 8.3.6 Effects of Make-up Air

The effects of make-up air included varying the location of the supply air during the static fire tests. During the background burns, it was determined that make-up air needed to be supplied to the compartments being desmoked. Make-up air was supplied by lifting the lower corner of the smoke curtain approximately 0.09 m<sup>2</sup> (1 ft<sup>2</sup>) at either 2-74-2 or 3-88-2. During selective manned tests, a desmoking member would raise the smoke curtain at WTD 2-74-2 up to 91 cm (36 in.) depending on conditions. He would "throttle" lower and lift the curtain according to the amount of smoke emitted from the compartment. From an analysis made on the percent recovery of transmittance, the location of the make-up air does not affect the performance of the fans (Figs. 74-79). In general, there was not a significant difference in the recovery between the two locations. Any variance may be due to wind conditions.

## 8.4 Post-Test Debriefing

Immediately after the manned tests, the desmoking team was debriefed. This discussion was led by the test team observer who was in Repair 4. All debriefings were recorded on video for documentation.

### 8.4.1 Results of Debriefing on the Red Devil Fan

The following is a summary of the comments made by the desmoking team on the Red Devil using both the 20.3 cm (8 in.) and 25.4 cm (10 in.) ducts. The members of the desmoking team found the 25.4 cm (10 in.) duct an improvement over the 20.3 cm (8 in.) duct with respect to removing smoke. However, maneuverability of the Red Devil was very awkward, and the 25.4 cm (10 in.) adapter made maneuverability even more difficult. The size and weight of the Red Devil made it difficult for one person to handle, especially on a vertical ladder. The maneuverability through doors and



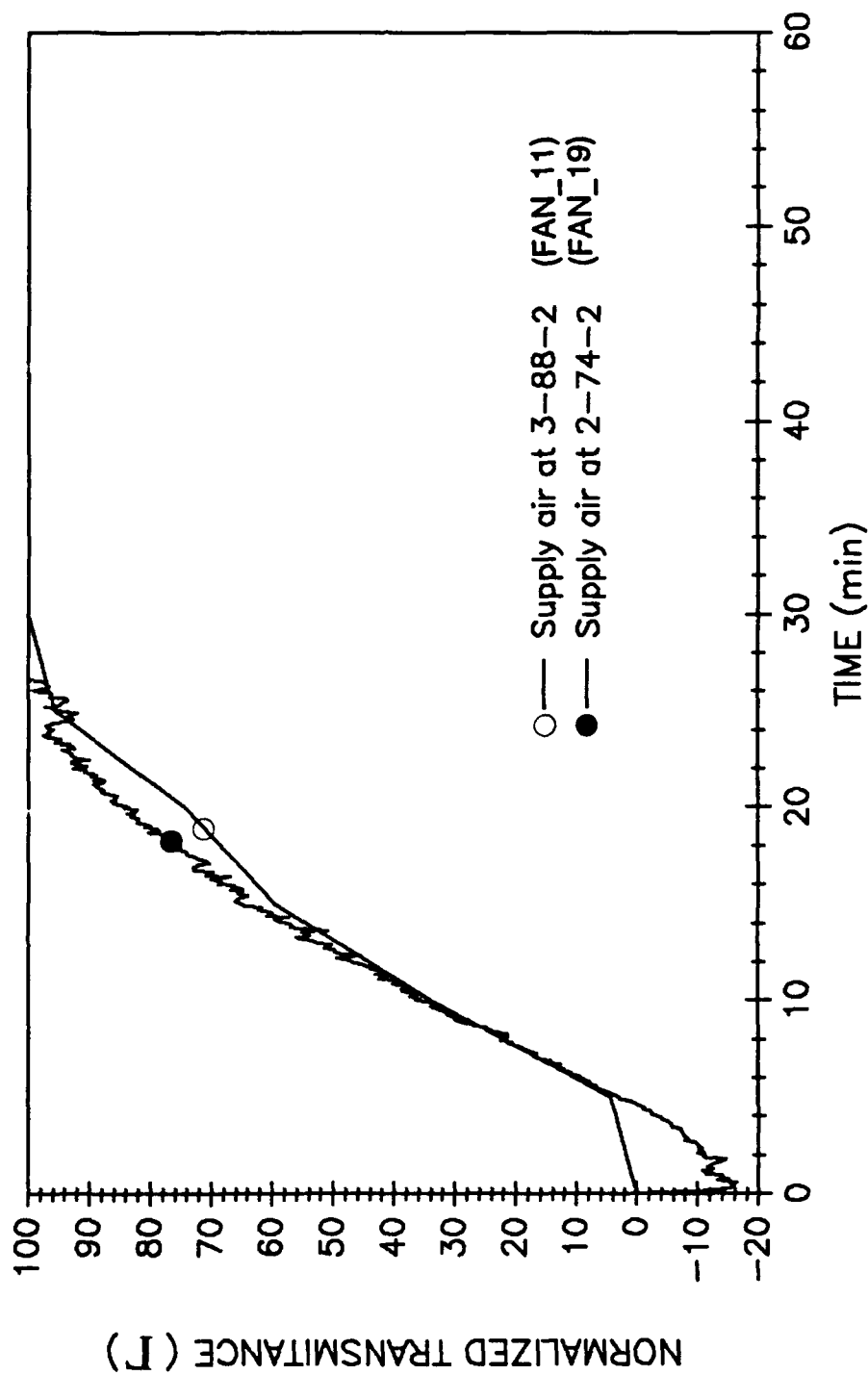


Fig. 74 - Recovery of normalized transmittance in RICER 1 at 2.30  
m level after fan is activated for Red Devil  
25.4 cm (10in) duct

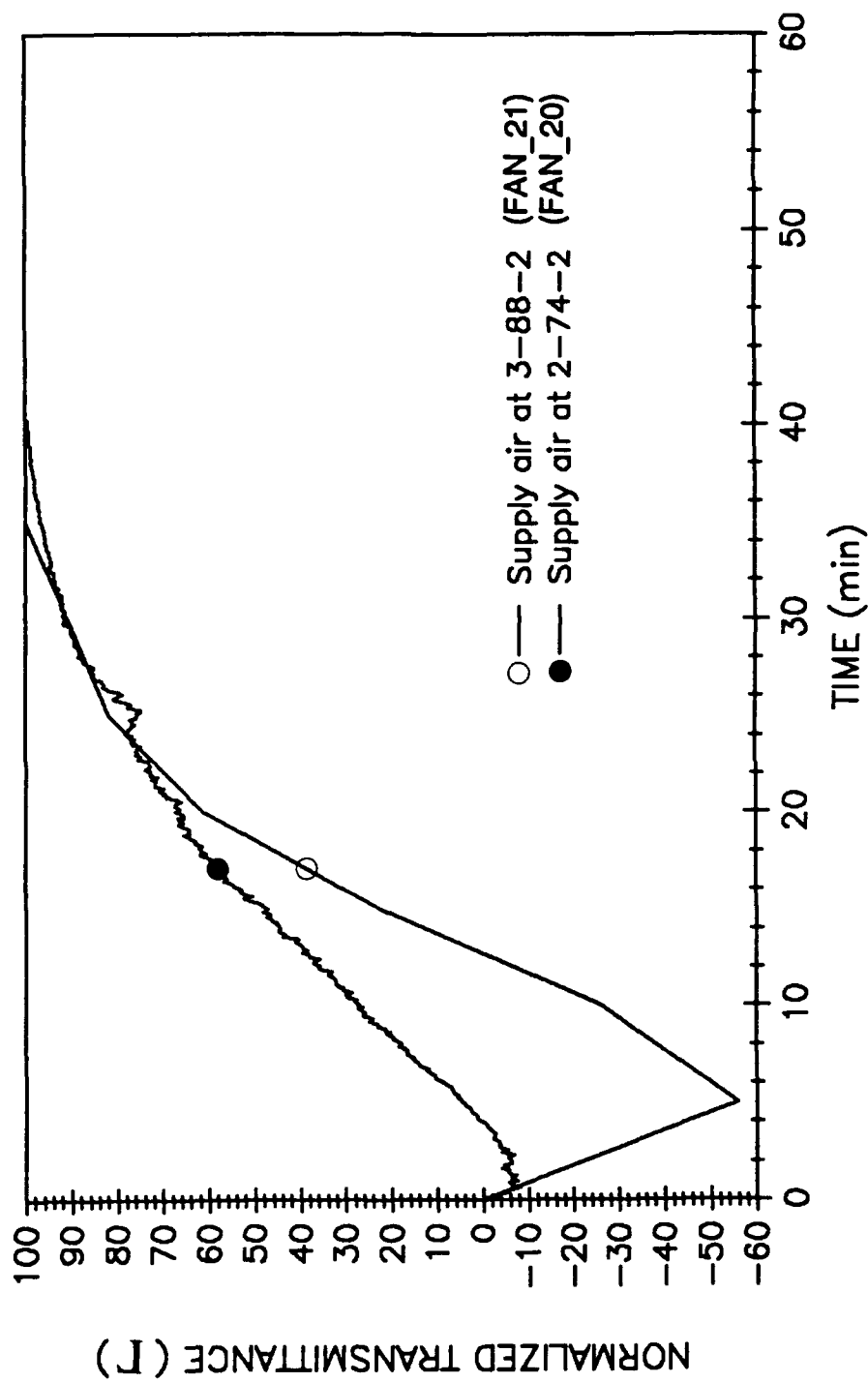


Fig. 75 - Recovery of transmittance in RICER 1 at 2.30 m level after fan is activated for RAMFAN 345 kPa (50 psi)

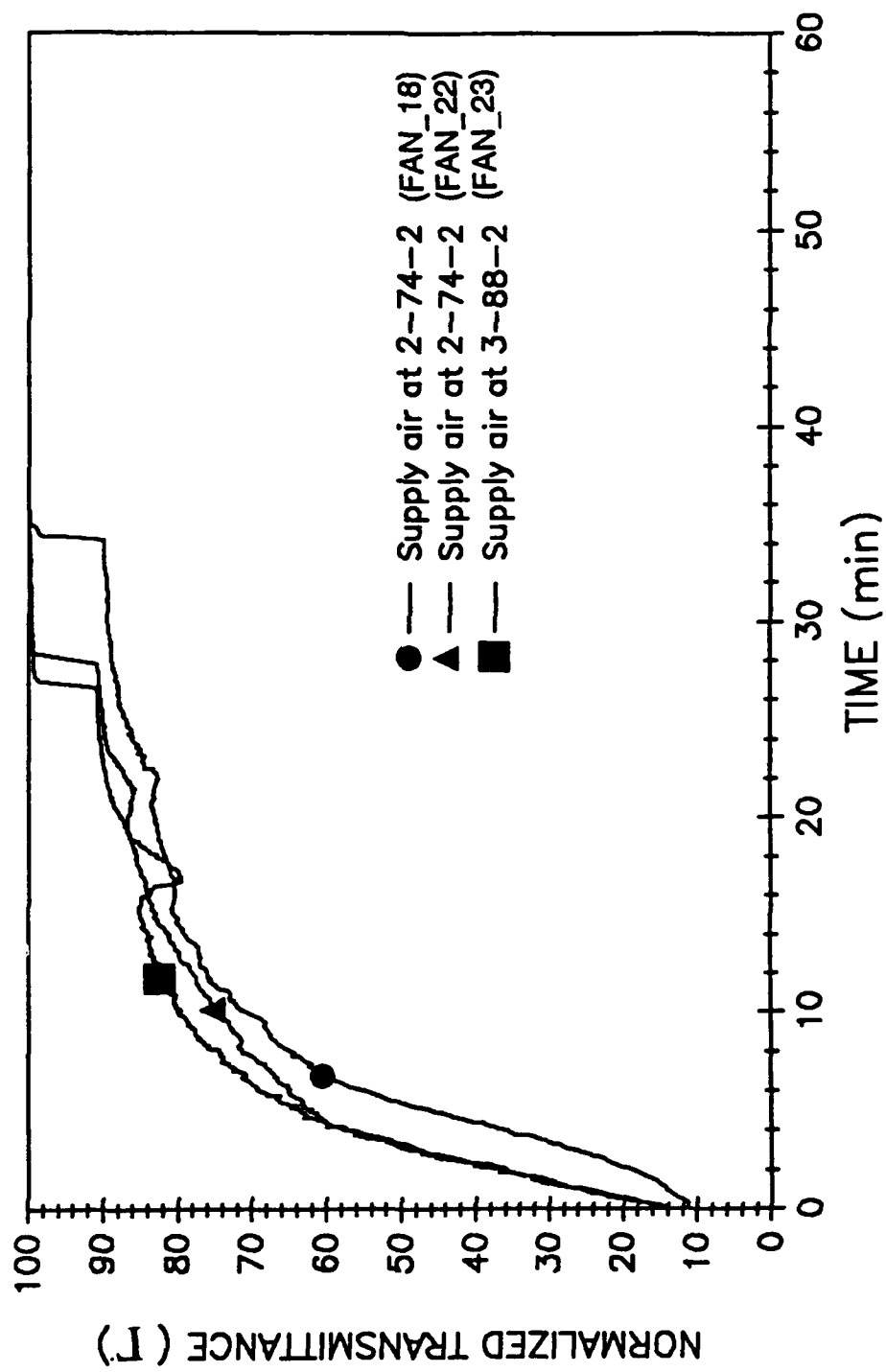


Fig. 76 - Recovery of transmittance in BERTHING 1 at 2.30 m level after fan is activated for RAMFAN 965 kPa (145 psi)

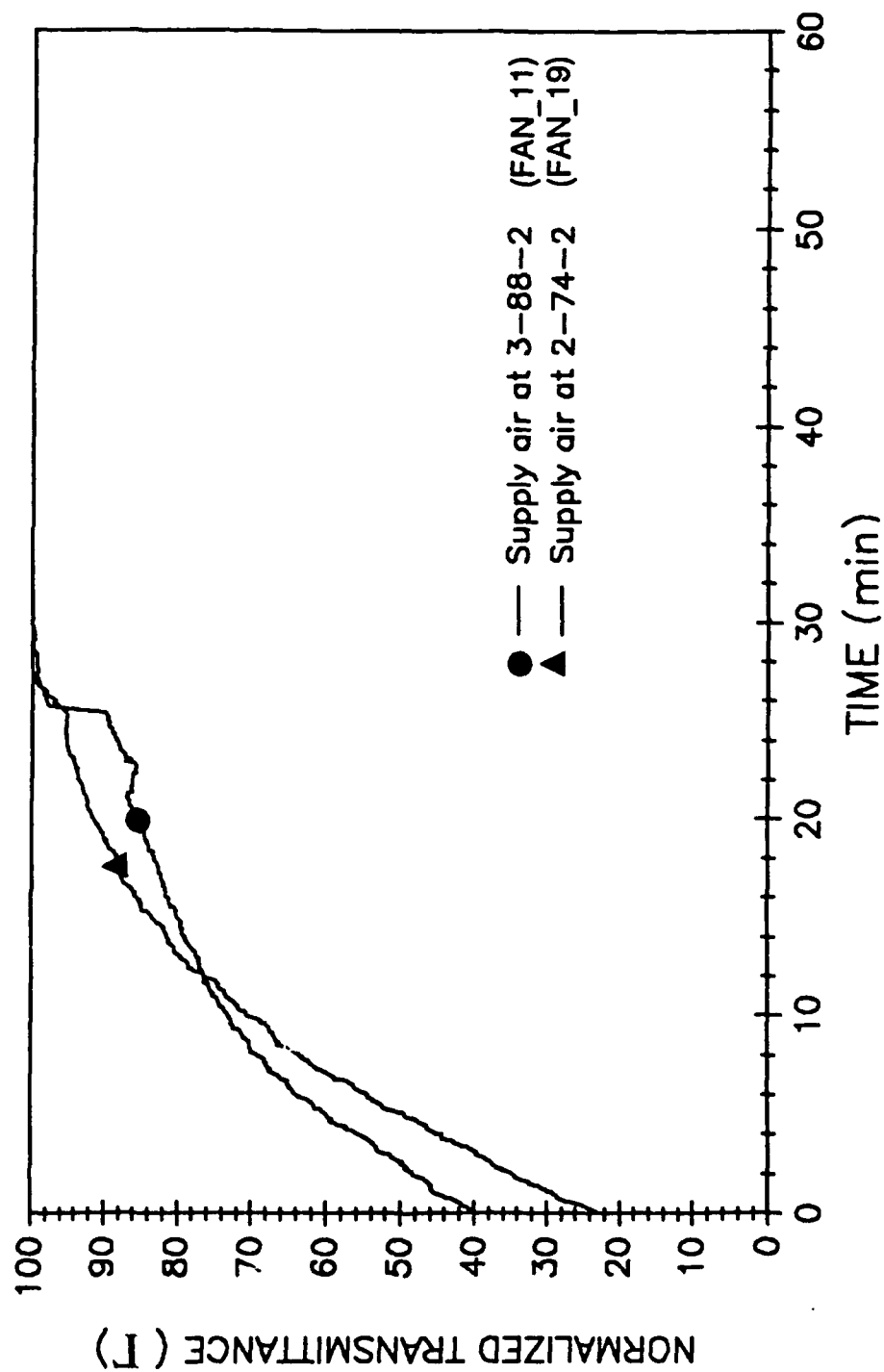


Fig. 77 - Recovery of normalized transmittance in BERTHING 1 at 2.30 m level after fan is activated for Red Devil 25.4 cm (10 in) duct

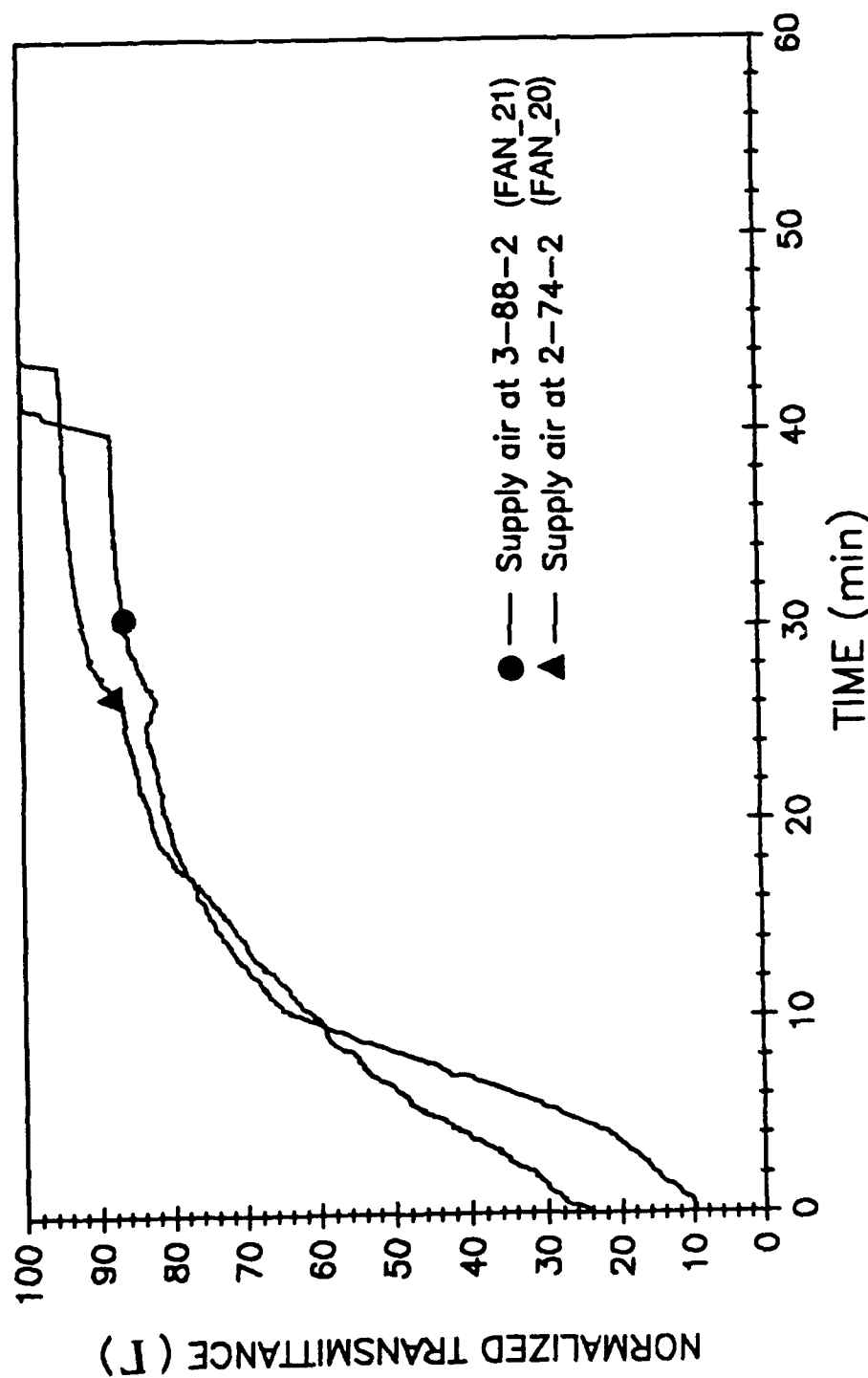


Fig. 78 - Recovery of transmittance in BERTHING 1 at 2.30 m level  
after fan is activated for RAMFAN 345 kPa (50 psi)

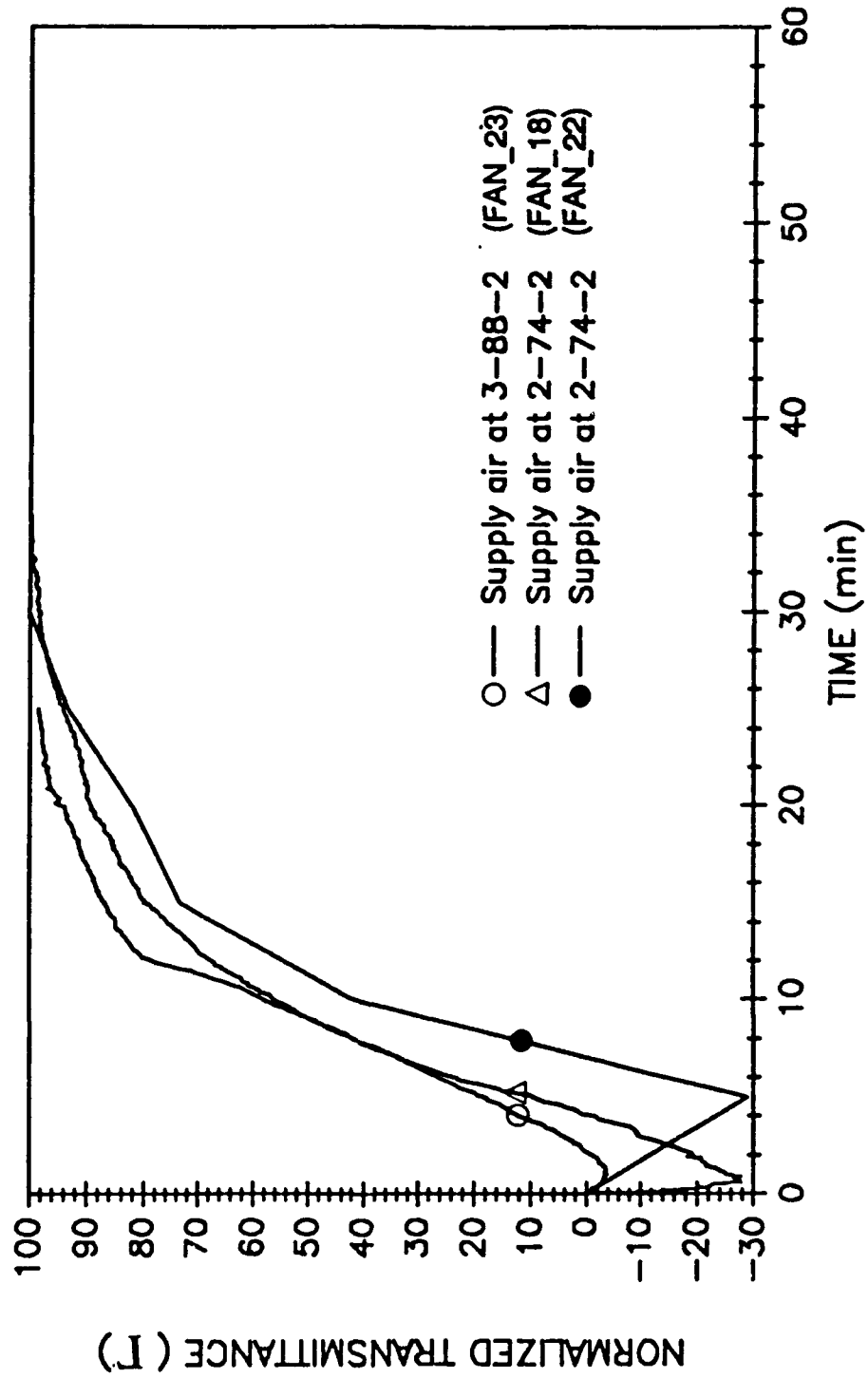


Fig. 79 - Recovery of transmittance in RICER 1 at 2.30 m level  
after fan is activated for RAMFAN 965 kPa (140 psi)

hatches was limited because of the overall diameter of the blower. The feet and extension cord on the fan further impeded the execution of installing the fan because they would become entangled in the rungs of the vertical ladder.

The desmoking team had difficulty attaching the exhaust and the ventilation ducts to the fan. There was no designation on the ducts specifying which end should be attached to the fan. Also, since the Red Devil is very quiet, it was necessary to check the discharge from the exhaust ducts to see if smoke was being moved or to feel the fan unit to see if it was operating. This is also a standard procedure taught in the Fire Fighting Schools when working with the Red Devil fan.

The members of the desmoking team felt that more training needed to be provided to utilize smoke curtains more efficiently in conjunction with the fans. At present, current doctrine requires a smoke curtain to be manned and to be tightly sealed; however, the desmoking fans require make-up air to desmoke an area effectively [12]. The bottom of the smoke curtain was raised approximately  $0.09 \text{ m}^2$  ( $1.0 \text{ ft}^2$ ) at 2-74-2 or 3-88-2. At times, the smoke curtain at WTD 2-74-2 would be raised and lowered from 91 cm (36 in.) to 30.4 cm (12 in.). This technique of "throttling" was used to increase the amount of make-up air so as to improve the efficiency of desmoking. There would, however, be a point where the smoke was not being contained in the compartment and emitted through the smoke curtain. During the Red Devil tests, the smoke curtain was not lifted very high because smoke leaked through the opening. However, during a Red Devil 20.3 cm (8 in.) duct test, smoke was emitted from the opening; therefore, the smoke curtain was sealed better around the edges to prevent the leakage of smoke.

#### 8.4.2 Results of Debriefing on the RAMFAN

The following is a compilation of the comments made by the desmoking team on the RAMFAN. The desmoking members found this fan easy to maneuver. One person was able to carry it down the vertical ladder with little difficulty because the fan is lighter and more compact. The desmoking team found that qualitatively the

RAMFAN appeared to remove smoke much better than the Red Devil, especially at high pressures. During FAN\_18, one of the members of the desmoking team entered RICER 1 and was able to see the smoke being drawn from BERTHING 1.

When operating, the RAMFAN was much louder than the Red Devil; however, the desmoking members were still able to communicate with each other. Because the desmoking team was able to hear the fan operate, it was not necessary to routinely check the RAMFAN to see if it was running as it was with the Red Devil.

After a number of tests, the desmoking members had difficulty attaching the ducts to the blower. The rims on the ducts became deformed which caused leakages around the fan because the integrity of the seal was not being kept. In addition, the inlet and outlet ducts for the RAMFAN could be easily confused. The inlet duct is made with a double coil support so that the duct does not collapse as it is drawing air or smoke. If the outlet duct, which is a single coil support, were to be used on the inlet side, the duct may collapse. At present, there is no easy way to identify the difference between the suction and discharge ducts.

The supply and the discharge water hoses occasionally kinked particularly at low flows. To keep the fan running at maximum power, hoses have to be kept free of kinks. The desmoking members also mentioned that the overboard discharge may be a problem in deep ships. This issue will be addressed later in the discussion section of the supplementary tests.

The desmoking team also noticed that the swivel connections on the fan would tend to fall at high pressures and tip the fan unit. This would also occur when there was a water pressure surge.

A ground line is supplied with the fans in case static electricity is built up from the movement of the air or smoke being drawn. In instances where there is a chance of explosion because of the gases being moved, the ground line becomes a



necessity. The problem associated with the ground line on the RAMFAN was that it was not long enough and would detach itself from where it was clipped.

The issue of the smoke curtains was again brought up. The desmoking members felt more training was needed to use the smoke curtains in conjunction with the blowers. However, during the WMF tests, a member of the desmoking team was able to lift the smoke curtain up to 91 cm (36 in.) without having smoke leak from the compartment. This suggests that the WMF is capable of moving a larger capacity than the Red Devil.

Overall, the members of the desmoking team preferred to use the RAMFAN compared to the Red Devil because it is easier to maneuver and does a better job, in their opinion, in desmoking an area. Even though the setup was more involved for the RAMFAN i.e., supply and discharge hoses must be connected, the desmoking members felt it took less time to rig this fan compared to the Red Devil. The two desmoking members could work on different aspects of rigging the fan. For example, one person was able to set the fan in place and rig the hoses while the other person rigged the ducts. In contrast, the Red Devil required two people to transport.

## 8.5 Conclusions

The smoke obscuration data from the static tests show that the RAMFAN at high inlet water pressure is most effective in clearing smoke as seen in Figs. 36-38. The RAMFAN at low inlet water pressure and the Red Devil equipped with the 25.4 cm (10 in.) duct are essentially equal in performance. The Red Devil equipped with the 20.3 cm (8 in.) duct is least effective. Since the water motor fan at high pressures clears smoke at a faster rate than the Red Devil, this directly affects the recovery of the oxygen also, thus, making compartments more accessible. As for cooling hot compartments with the desmoking fans, there was no significant difference between natural smoke settling and using the desmoking fans with respect to decrease in temperature in the compartments during these tests. This may be attributed to the compartments naturally cooling before desmoking is initiated because the 15.14  $\ell$  (4

gal) heptane fire was out before the fans were activated. Also, the reradiation from the steel ducts, overhead, and bulkheads kept the compartment air hot (oven effect).

From the one natural venting test conducted, it is not advisable to desmoke naturally while the fire is still burning because temperature and percent transmittance do not recover as quickly.

When the fans are used to desmoke an area, make-up air needs to be supplied as determined from the background burns. Since the compartments that were being desmoked could be considered "sealed," an opening had to be created. This was done by lifting the smoke curtain  $0.09 \text{ m}^2$  ( $1 \text{ ft}^2$ ) which allowed fresh air into the compartments. Two locations were tested during this series, WTD 2-74-2 and 3-88-2; neither location proved to be better than the other. Logistically, it may be much more difficult to provide make-up air remotely, e.g., communications would have to be maintained between the make-up air location and the exhaust point.

The members of the desmoking team preferred to use the RAMFAN as opposed to the Red Devil because it desmoked the area more efficiently. They also preferred the Red Devil equipped with the 25.4 cm (10 in.) adapter because of its improved desmoking ability over the 20.3 cm (8 in.) duct even though it is more cumbersome. The RAMFAN was also easier to maneuver since it is lighter and has a smaller overall diameter. Even though there were more steps involved in rigging the RAMFAN's supply and discharge water hoses, the time to install the RAMFAN was generally less than or equal to the Red Devil. The RAMFAN operated much louder than the Red Devil; however, the desmoking team thought this was an asset because one could hear the fan running as compared to the Red Devil where one had to feel the unit to see if it was running. Also, if the hoses became kinked, one could hear the fan wind down. The loud whirling did not hinder communications between the desmoking members.

## 9.0 DYNAMIC FIRE TESTS

Table 7 is a summary of the dynamic fire tests that were performed. A 3.8  $\ell$ pm (1 gpm) diesel spray fire was used during these tests. Ten tests were conducted which included four using the Red Devil, four using the RAMFAN, one test using natural ventilation, and one investigating natural smoke settling. FAN\_26 and 27 will be discussed in the Supplementary Tests section. The rationale for conducting these tests were to determine if the fans were capable of removing larger quantities of smoke and heat compared to the static tests where the smaller fire was extinguished. During the manned tests, desmoking was not initiated until the fire in BERTHING 2 was out. This was done for safety. In the unmanned tests, the desmoking fan was activated at ignition. These were performed to determine the impact of ventilation while the fire was still burning (dynamic). Currently, this tactic is not recognized in technical manuals or taught in damage control schools.

### 9.1 Setup

The setup of the fire tests was similar to the static fire tests. The same compartments and vent configuration were used. Combustion air to the fire compartment was supplied via a Typhoon fan at WTD 3-88-2 which was on prior to the fire test. A smoke curtain was closed around the drum cowling of the Typhoon.

The smoke meters in BERTHING 1 were removed because of the possible damage from the greater heat that was generated.

Figure 80 shows the setup of the unmanned dynamic desmoking configuration. For the unmanned tests, the two 4.6 m (15 ft) sections of supply duct were pre-hung from the smoke curtain at WTD 2-74-2. The three 4.6 m (15 ft) sections of exhaust duct were also prepositioned. The power supply for the Red Devil and the water supply and discharge for the RAMFAN were run in the same manner as the static tests.

Table 7. Dynamic Fire Tests

<u>Test</u>	<u>Fan/Duct</u>	<u>Inlet Pressure</u>	<u>Manned/ Unmanned</u>
FAN_24	RAMFAN	992 kPa (144 psi)	M
FAN_25	Red Devil 25.4 cm (10 in.)	--	M
FAN_28	RAMFAN	861 kPa (125 psi)	M
FAN_30	Red Devil 25.4 cm (10 in.)	--	U
FAN_31	Red Devil 20.3 cm (8 in.)	--	U
FAN_32	RAMFAN	965/345/965 kPa (140/50/140 psi)	U
FAN_33	RAMFAN	345 kPa (50 psi)	U
FAN_34	Red Devil 20.3 cm (8 in.)	--	U
FAN_35	--	--	U
FAN_36	--	--	U

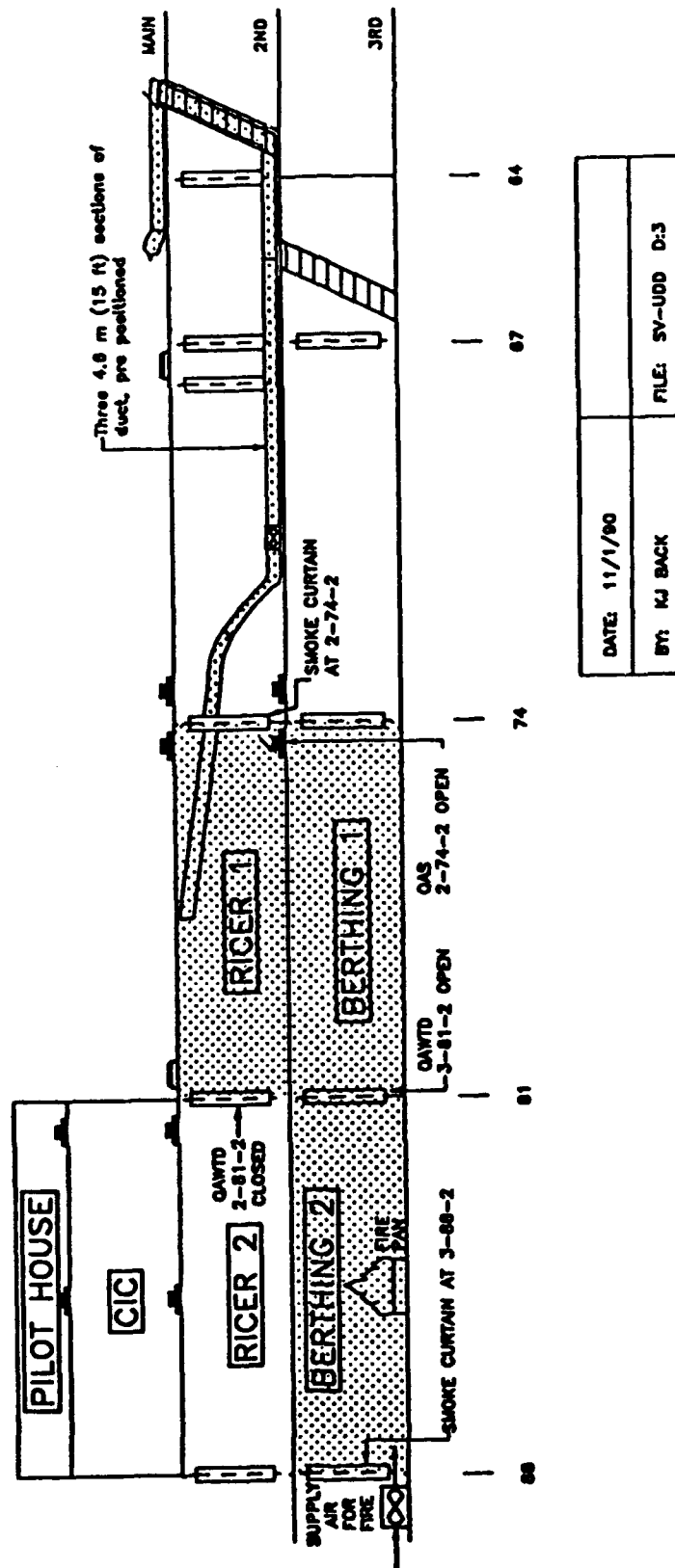


Fig. 80 - Section view, unmanned dynamic desmoking

In the manned static tests, the two members of the desmoking team and the test team observer were staged in Repair 4, where they awaited orders to commence desmoking the compartments. They hung the two sections of suction duct at the smoke curtain at WTD 2-74-2 and enclosed the smoke curtain around the duct with clamps. The scuttle at 1-75-2 was propped open during the burn phase to allow smoke and heat to travel through the test area. Figure 81 shows the setup prior to desmoking.

## 9.2 Procedures

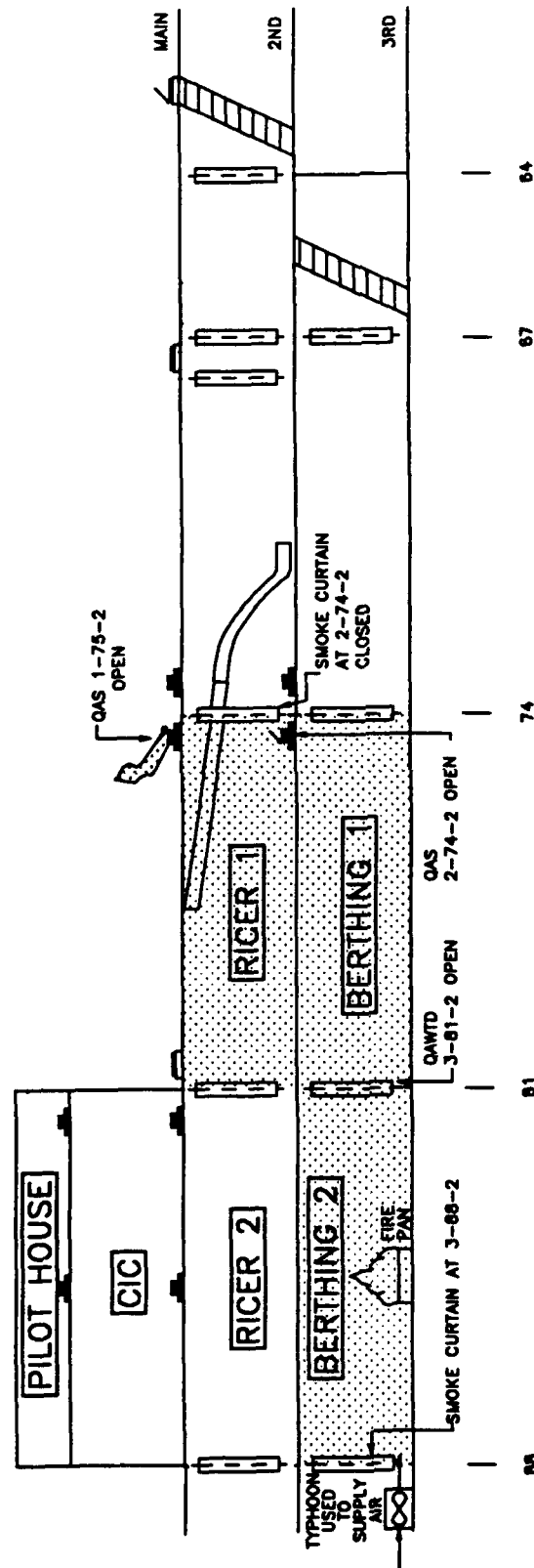
Prior to each test, the fire area was cleared of all personnel. The safety officer patrolled the aft section of the ship. Two persons positioned at the well deck poured and ignited the 15.14  $\ell$  (4.0 gal) of heptane that was used as a preburn. The quarter-turn valve to the diesel system was then opened. Three minutes after ignition, diesel fuel was sprayed into the pan at a rate of 3.8  $\ell$ pm (1.0 gpm). Air was supplied by the Typhoon fan at 3-88-2 to allow combustion of the fuel. After 7 minutes of diesel fuel flow, the diesel fuel flow was secured and the fuel line blowdown.

### 9.2.1 Unmanned

In the unmanned tests, the blowers were pre-staged before the test and activated prior to ignition, i.e., the desmoking fan and the Typhoon supplying combustion air continued to operate continuously during the burning phase and desmoking phase. The Typhoon fan was allowed to run during the desmoking phase to supply combustion air to the fire.

### 9.2.2 Manned

In the manned tests, the desmoking team and the test team observer staged in Repair 4 were called to desmoke the area after the diesel fuel was secured and the system blowdown. The Typhoon that was supplying combustion air and the scuttle



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Fig. 81 - Section view, manned dynamic test set-up prior to desmoking

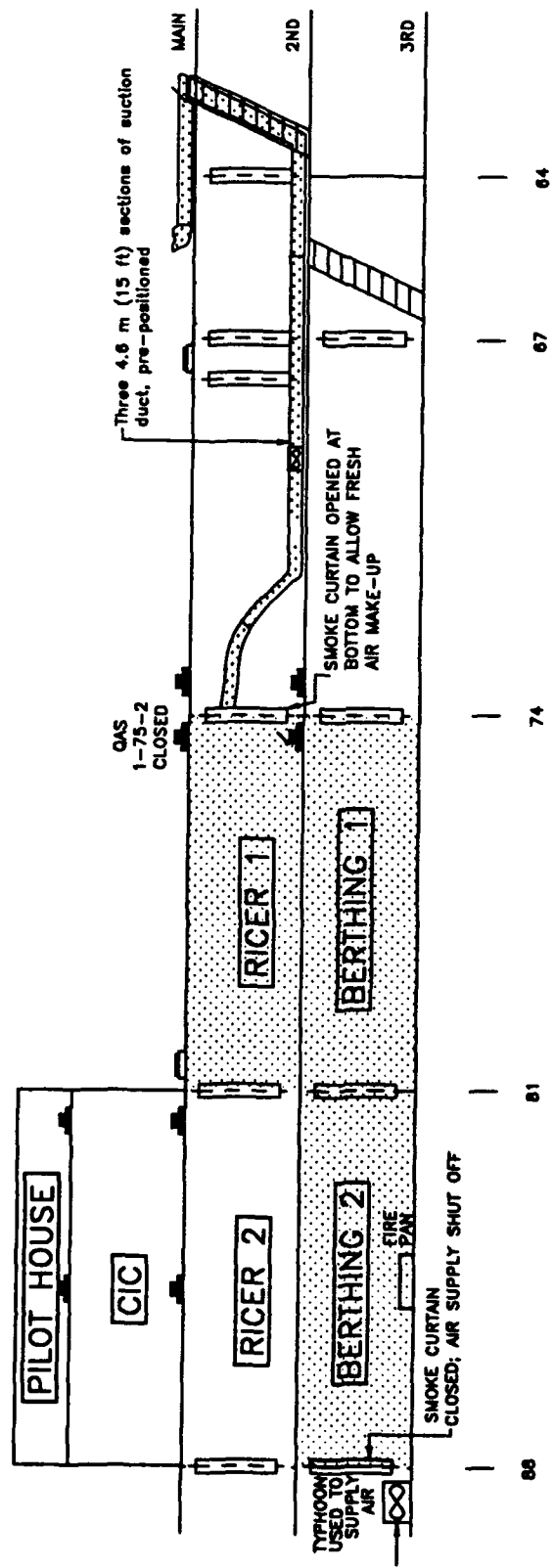
at 1-75-2 that was opened during the burning phase were also secured at this time. The desmoking members dressed in the same fashion as in the static tests, proceeded in the same manner. They installed the equipment as shown in Fig. 82. Figures 83 and 84 show the setup of the suction duct at WTD 2-74-2.

### 9.3 Results

Figures 85-87 show the percent transmittance for a Red Devil, WMF, and natural venting tests, respectively. No difference in desmoking capability in the manned tests is evident between the Red Devil with 25.4 cm (10 in.) ducts (FAN\_25) and the RAMFAN at high pressures (FAN\_28). Figure 88 shows the percent recovery rate of the Red Devil 25.4 cm (10 in.), the RAMFAN 965 kPa (140 psi), and natural venting. When comparing the performance of these fans with natural venting, there is not a significant difference in recovery rates for the first eight minutes. However, after the eight minutes the recovery rate of the natural venting tapers off but recovers at the same time as the fans' recovery rate. Unfortunately, the smoke meters in BERTHING 1 were removed because of the possibility of damage from the intense heat. More insight would have been provided if the amount of smoke in BERTHING 1 was known.

The dynamic unmanned fire tests were more difficult to analyze. Since both the desmoking fan and the Typhoon fan were on at ignition, there was no basis as to how much smoke was in the compartment initially. Hence, a recovery of smoke could not be determined. Also, since the Typhoon was on during the entire test, it was uncertain if the smoke in the compartments was dissipating because of the Typhoon pushing the smoke through the compartments or the desmoking fans pulling the smoke.





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Fig. 82 - Section view, manned dynamic tests during desmoking

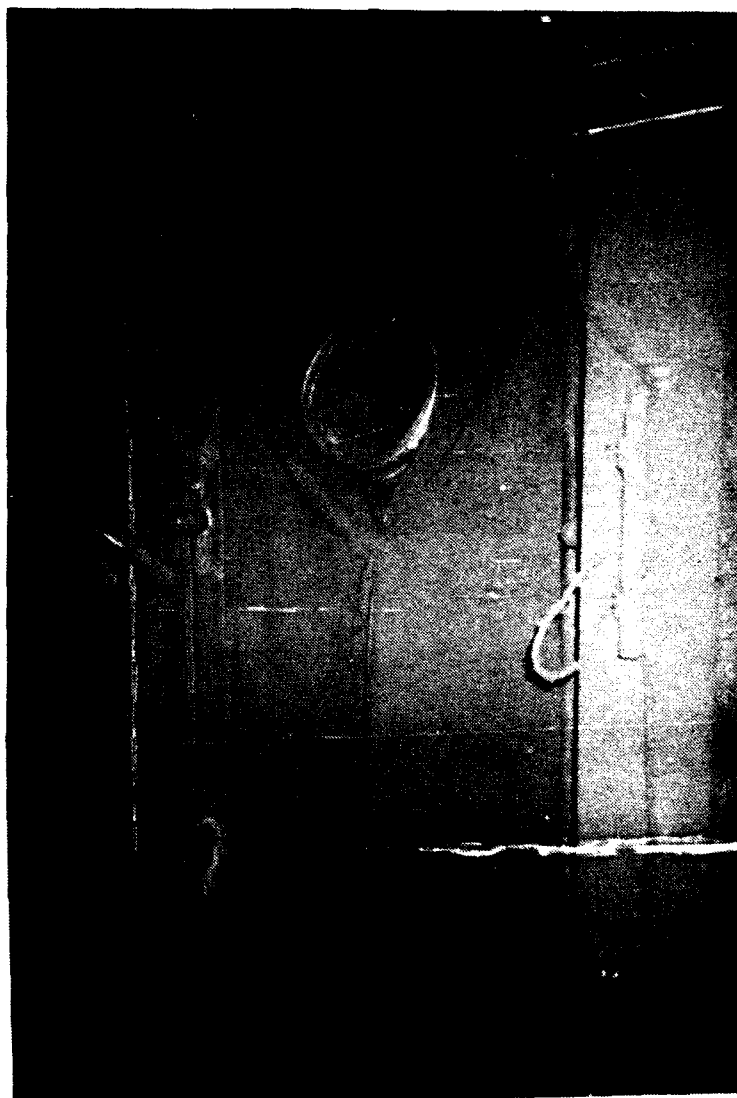


Fig. 83 - Typical configuration of suction duct at 2-74-2  
(Viewed from inside RICER 1)



Note: Clips were used to secure the smoke curtain at the door and to enclose the opening for the duct. Make-up air was supplied at the lower left corner by detaching the clips

Fig. 84 - Configuration of suction duct at 2-74-2

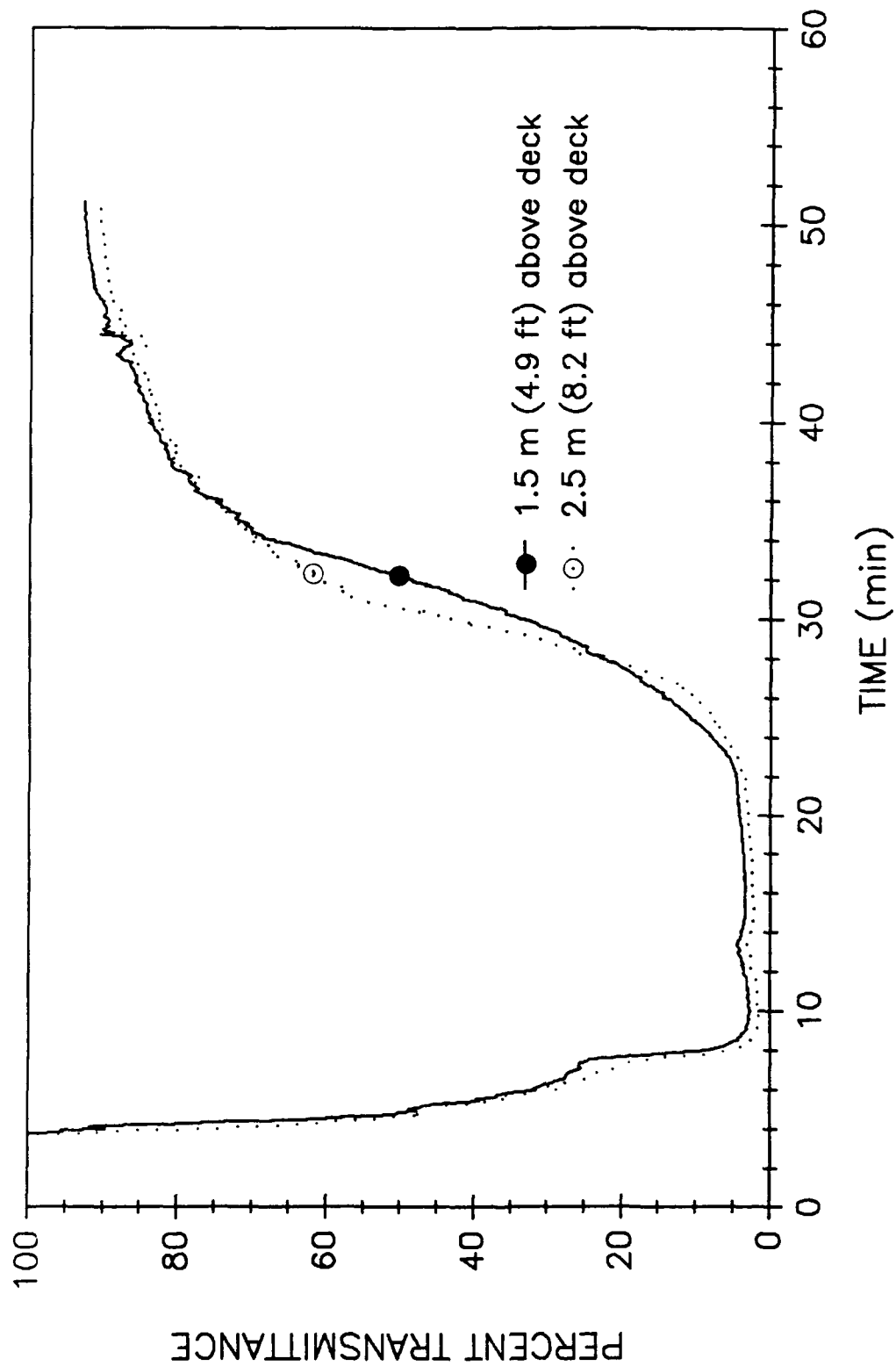


Fig. 85 - Percent transmittance in RICER 1 during FAN\_25  
using Red Devil 25.4 cm (10 in) duct

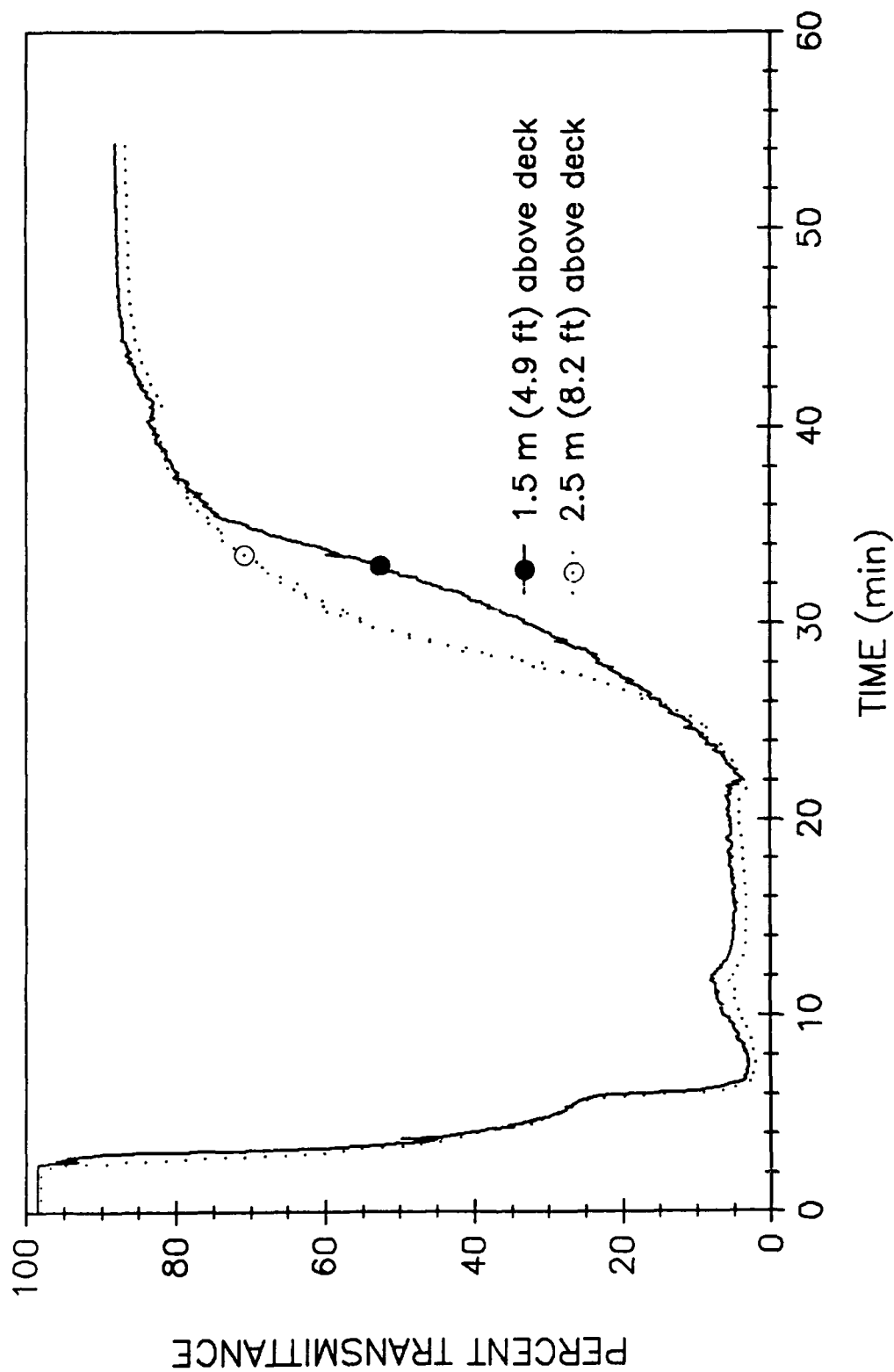


Fig. 86 - Percent transmittance in RICER 1 during FAN\_28  
using RAMFAN 965 kPa (145 psi) supplied by P-250

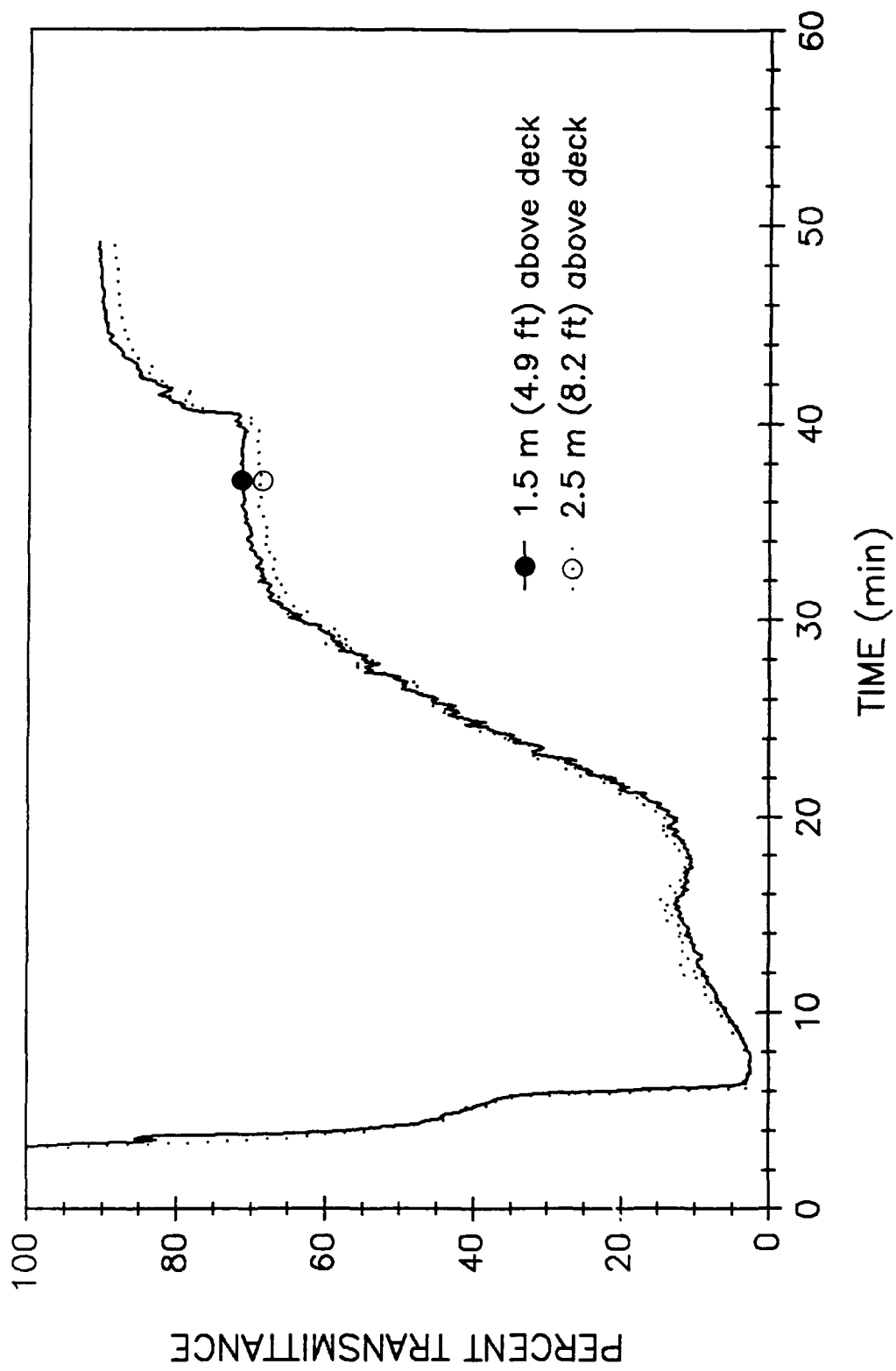


Fig. 87 - Percent transmittance in RICER 1 during FAN\_35  
using natural smoke venting

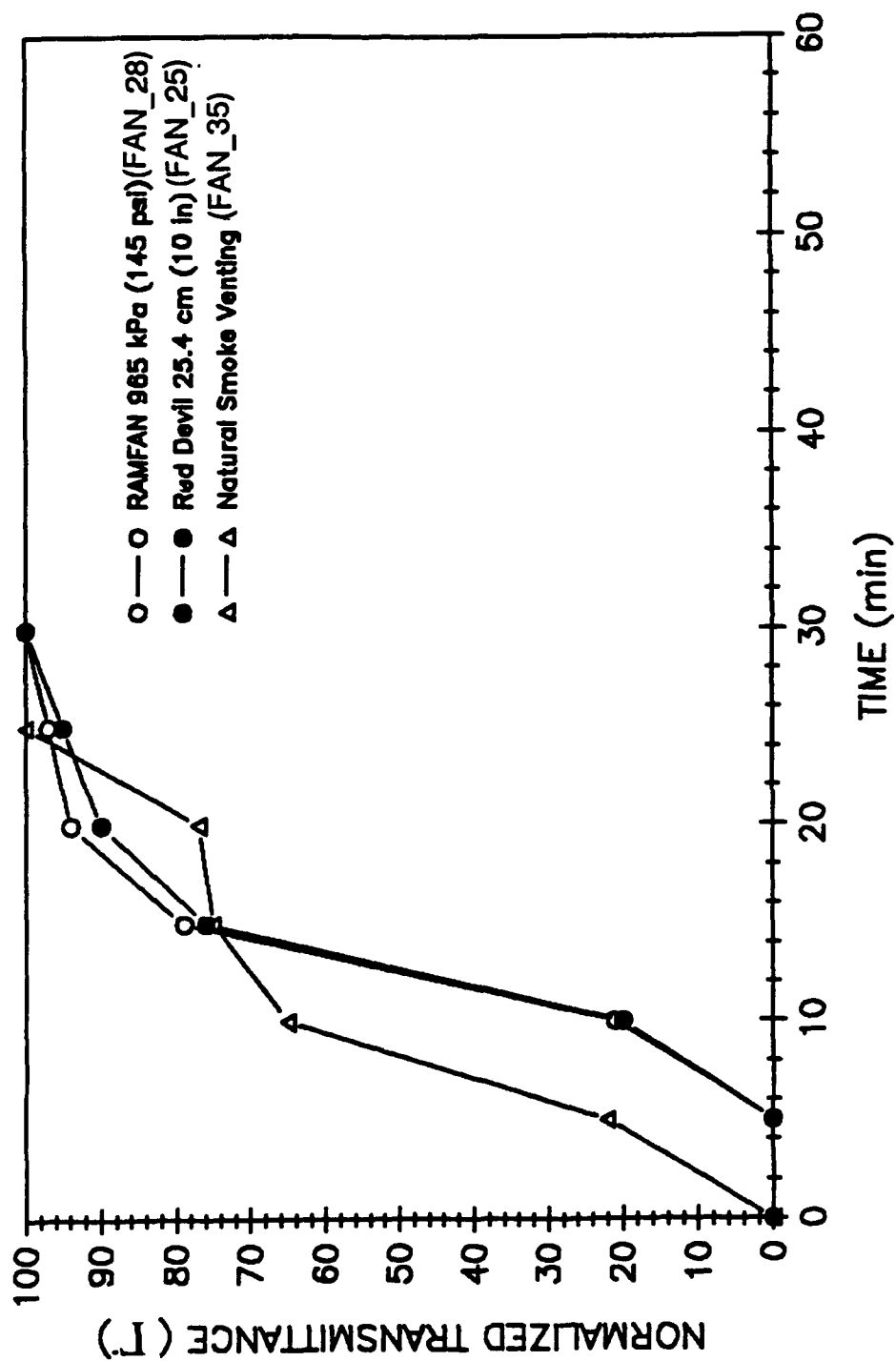


Fig. 88 - Recovery of normalized transmittance at 2nd deck - 2.5 m level after fan is activated

## **9.4 Post-Test Debriefing**

Debriefings were held after the dynamic manned tests. The following are some additional comments that the desmoking personnel had on the RAMFAN and the Red Devil.

### **9.4.1 Results of Debriefing on the RAMFAN**

The desmoking members felt the RAMFAN worked as well for the dynamic tests as in the static tests. The smoke curtain at 2-74-2 was raised up to 66 cm (26 in.) from the standard 30.5 cm (12 in.), momentarily. There was a sufficient amount of suction that kept the smoke from leaking out of RICER 1. In fact, one of the desmoking personnel felt air being drawn into RICER 1. The desmoking team felt the placement of the suction duct seemed to make the RAMFAN draw better.

As mentioned before, the rims on the ducts were flimsy and smoke escaped from the fan at the connection. The desmoking members noticed during FAN\_24 that the fan was physically rolling over (tipping) from the supply hose pushing against the fan. The swivel connection had to be adjusted so that the fan would not tip over.

### **9.4.2 Results of Debriefing on the Red Devil Fan**

The desmoking members did not feel the Red Devil using the 25.4 cm (10 in.) duct worked as well as the RAMFAN for the dynamic tests. The smoke curtain was raised in a similar manner as in FAN\_24. Smoke was being emitted from the opening unlike FAN\_24 where air was being drawn into RICER 1.

## **9.5 Conclusions**

The rationale for conducting these tests was to see if the fans were capable of removing smoke as fast as it was being produced. From the results, it was not certain that the fans were able to perform this task. However, from a qualitative



standpoint, it did not seem that the fans were able to desmoke an area if the fire was still burning. In some cases, it would make the non-fire compartments smokier than if there were no desmoking fans used.

## **10.0 SUPPLEMENTARY TESTS**

The RAMFAN was utilized in the following supplemental tests: a water mist test, a "lift" test, a test using the P-250 pump to supply the WMF, a brackish water test, and a heat stress test. An additional water mist test was performed using the Hale Typhoon III.

### **10.1 Water Mist Tests**

The water mist tests were performed to examine the cooling effects and feasibility of using the integral spray nozzle to cool a compartment. Two cooling tests were performed using the RAMFAN and the Hale Typhoon III fan, both equipped with an integral water spray nozzle. The RAMFAN was equipped with a 24.6  $\ell$ pm (6.5 gpm) water spray nozzle (other size nozzles may be substituted) while the Hale Typhoon III was equipped with a 7.6  $\ell$ pm (2 gpm) spray nozzle. Table 8 is a summary of the flow tests that were performed prior to the cooling tests. The RAMFAN was tested during the flow test with and without the mister and with and without the cone. The Hale Typhoon III was tested with and without the mister.

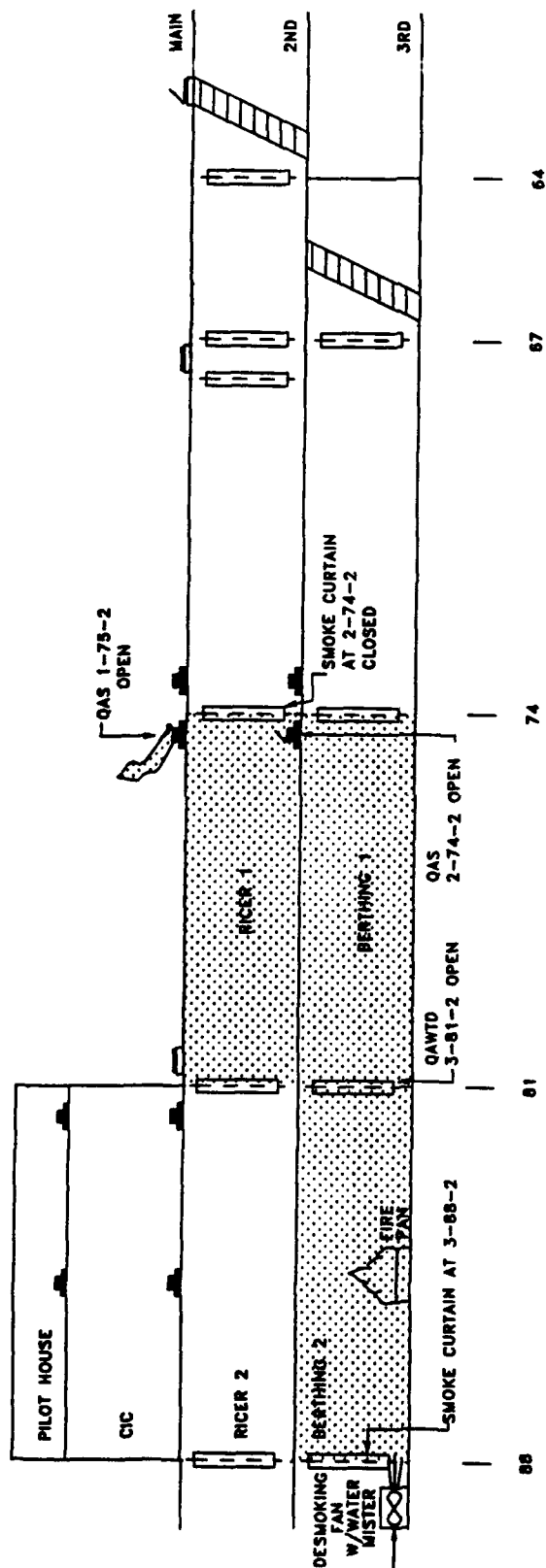
#### **10.1.1 Setup and Procedures**

Figure 89 shows the setup of these tests. QAWTD 3-81-2, QAS 2-74-2, and QAS 1-75-2 were open to vent the smoke out to the main deck. The water misting fans were used at WTD 3-88-2 through a smoke curtain. No ducts were used during

Table 8. Desmoking Fan Flow Test with Mister

<u>Scenario</u>	<u>Fire Main Pressure/Flow</u>	<u>Fan Inlet Pressure</u>	<u>Mister Nozzle Size</u>	<u>Air Discharge</u>	<u>Air Suction</u>
		<b>RAMFAN</b>			
Mister on	<u>1006 kPa</u> 255 $\phi$ m	985 kPa (143 psi)	Bete TF10N (50°) 24.6 $\phi$ m (6.5 gpm) @ 689 kPa (100 psi)	NR	NR
Mister off	<u>627 kPa</u> 193 $\phi$ m	649 kPa (94 psi)		NR	NR
Mister on	<u>627 kPa</u> 212 $\phi$ m	640 kPa (93 psi)		NR	NR
with cone (mister on)	246 $\phi$ m	985 kPa (143 psi)		8,930 $\phi$ m (316 cfm)	34,958 $\phi$ m (1,237 cfm)
without cone	246 $\phi$ m	985 kPa (143 psi)		11,643 $\phi$ m (412 cfm)	26,790 $\phi$ m (948 cfm)
		<b>Hale Typhoon 3</b>			
Mister off	<u>1006 kPa</u> 386 $\phi$ m	854 kPa (124 psi)	3.8-7.6 $\phi$ m (1-2 gpm) spray nozzle	NR	NR
Mister on	<u>1006 kPa</u> 393 $\phi$ m	868 kPa (126 psi)		NR	NR

NR = not recorded



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Fig. 89 - Section view - water mister test

these tests. The members of the desmoking team were standing by in the well deck ready to be called away. Water to the RAMFAN and the Typhoon III were supplied at FPL 3-95-2 with 1 length of 15.3 m (50 ft) hose. The discharge from the fan was fed back to the well via 1 length of 15.3 m (50 ft) hose.

For the water mist tests, the same size fire and procedures were used as in the dynamic tests. Fifteen and four tenths liters (4 gal) of heptane was used for the preburn. The heptane was allowed to burn for three minutes, and then the diesel spray, set at 3.8  $\ell$ pm (1.0 gpm), was initiated. After five minutes of diesel spray, the fuel was secured. The desmoking team was then called away to remove the large Typhoon fan supplying air to the fire compartment and to install the water mister at 3-88-2 which was prerigged with its supply and discharge hoses. By rotating the fan unit, the spray of the nozzle was directed at the residual flames, bulkhead, and the decks. This was continued until the residual flames were extinguished.

#### 10.1.2 Results

Figures 90-93 show the compartment air temperatures in BERTHING 2 at FR 83 using the various desmoking fans. As mentioned earlier in this analysis, a significant cooling effect was not seen when the desmoking fans were used to draw the smoke/air away from the compartments (Figs. 90 and 91). However, a significant impact was seen when the RAMFAN with the integral water mist attachment was used. During this test, FAN\_26, the RAMFAN with the water mister extinguished the residual flames and decreased the temperature almost 300°C (572°F) in one minute to near ambient temperatures (Fig. 92).

Figure 93 shows the decrease in compartment air temperatures when the Hale Typhoon III fan was used. Temperatures in the compartment were decreased; however, the rate of decrease is not as dramatic as the RAMFAN.

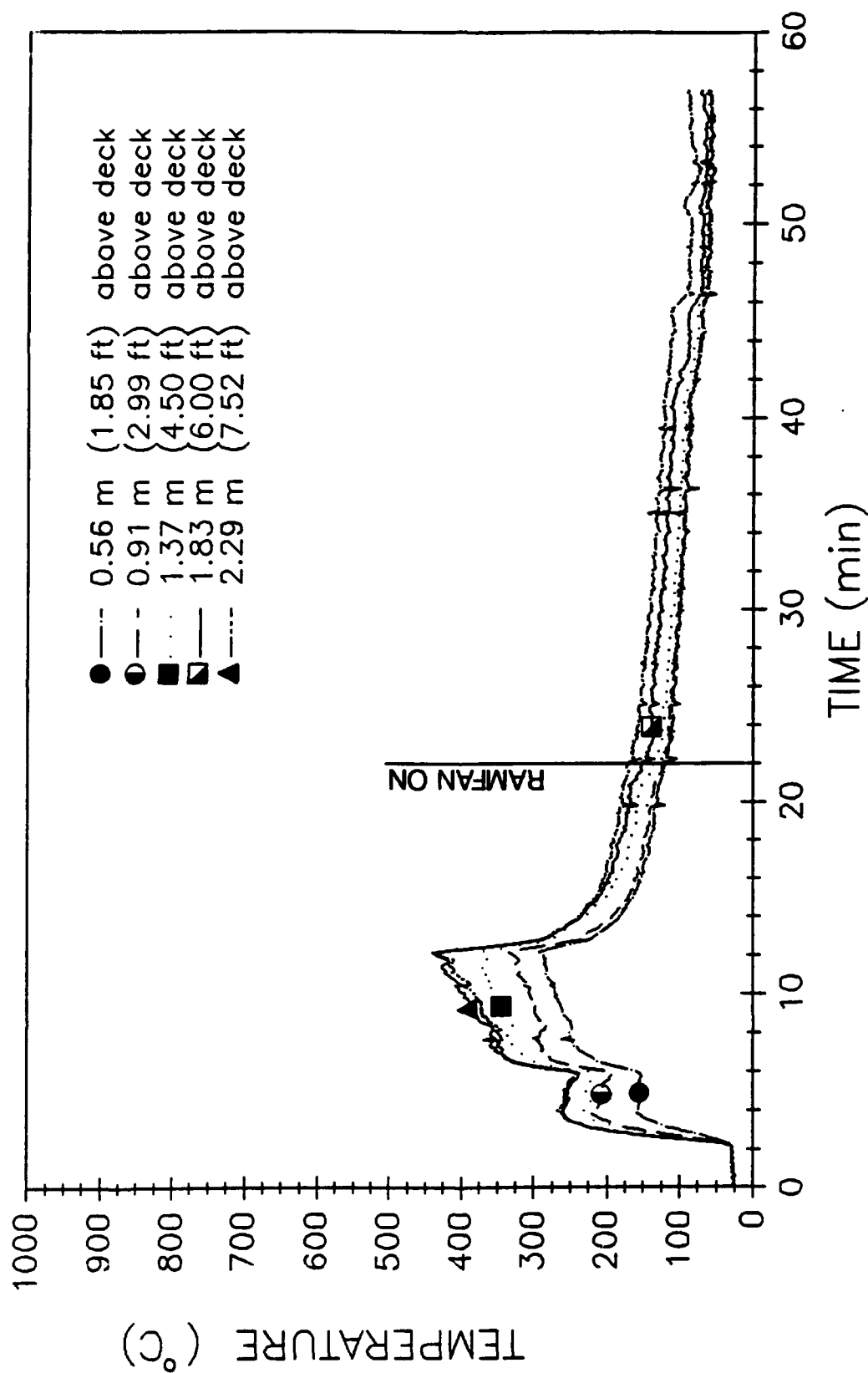


Fig. 90 - Temperature in BERTHING 2 (3-83-6) during FAN\_24 using RAMFAN at 965 kPa (144 psi)

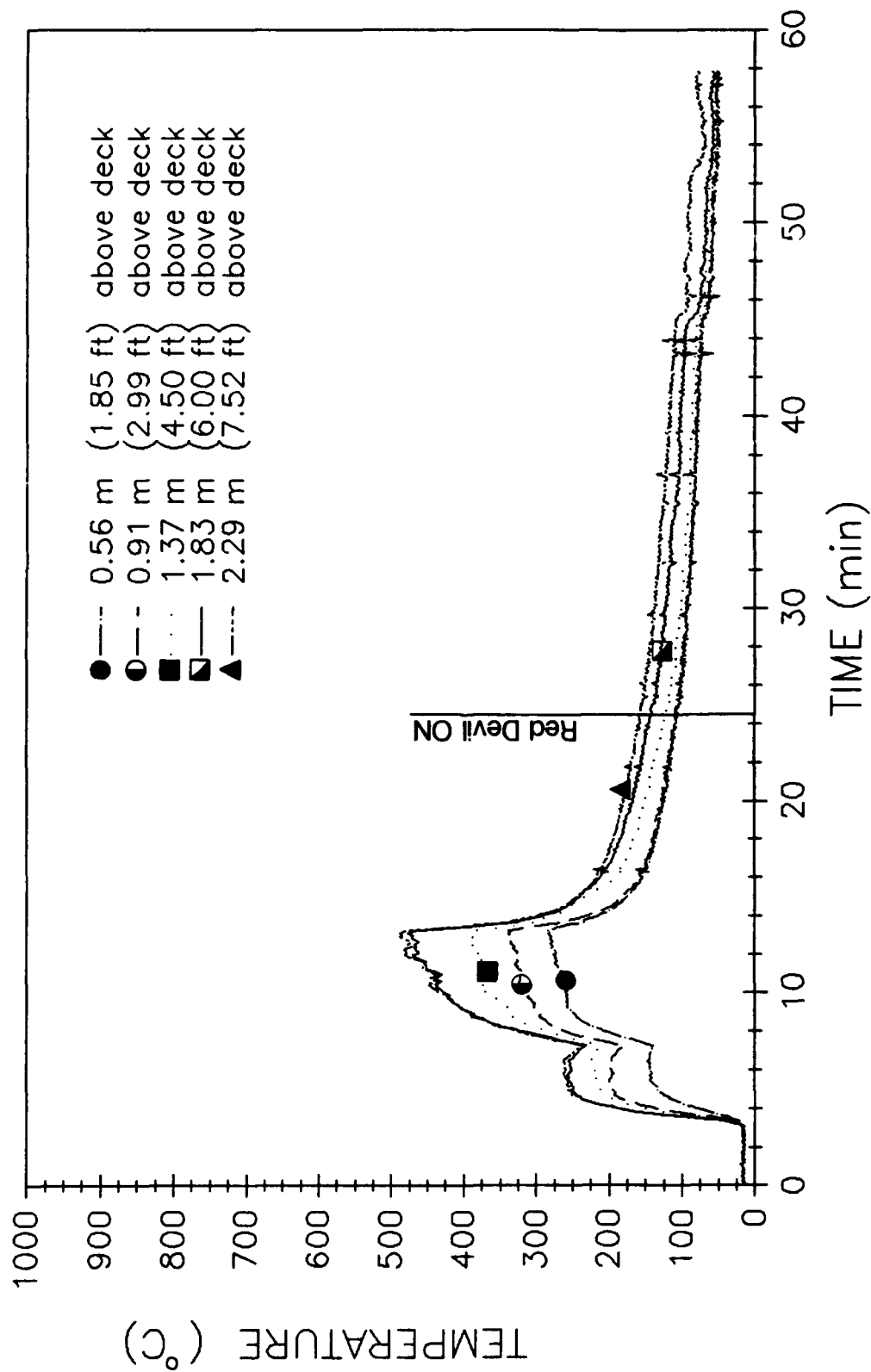


Fig. 91 - Temperature in BERTHING 2 (3-83-6) during FAN\_25  
using Red Devil 25.4 cm (10 in) duct

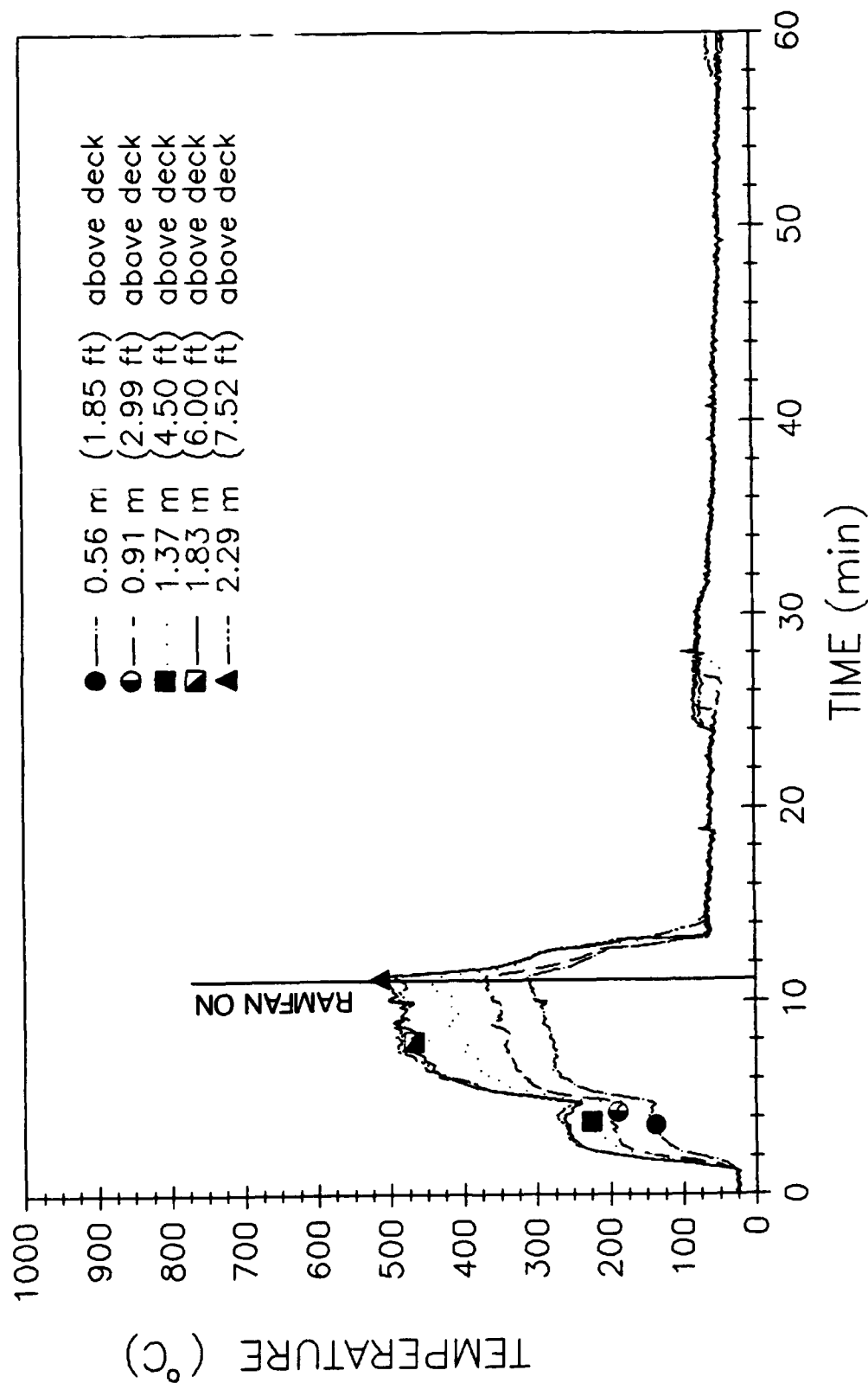


Fig. 92 - Temperature in BERTHINC. 2 (3-83-6) during FAN\_26 using RAMFAN 965 kPa (140 psi) with water mister

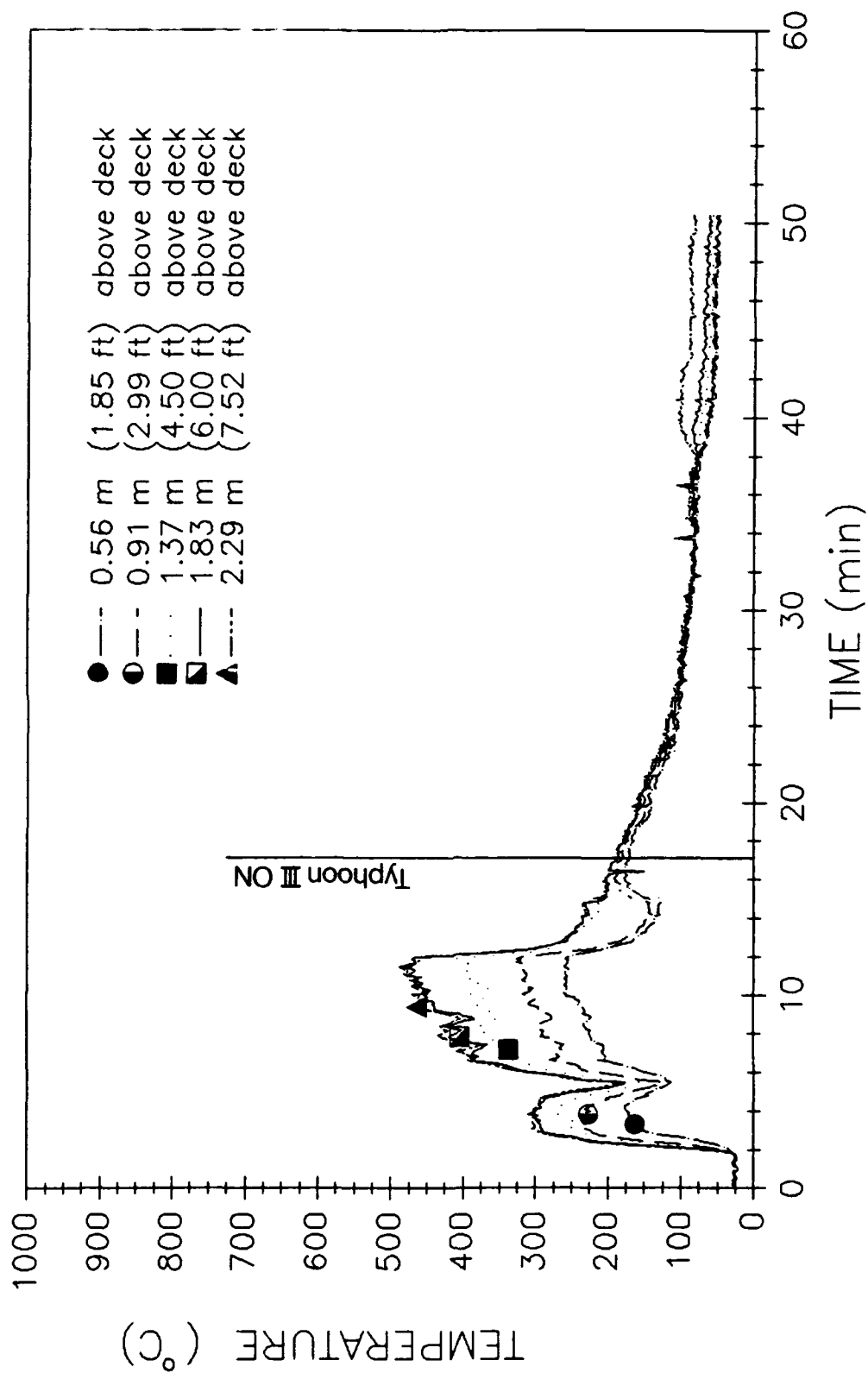


Fig. 93 - Temperature in BERTHING 2 (3-83-6) during FAN\_27



The average bulkhead temperatures at 3-88-2 and 3-81-2 are shown in Figs. 94 and 95. In Fig. 94, neither desmoking fan with the spray nozzle offers any cooling capability at bulkhead 3-88-2 over the other two desmoking fans. However, the temperatures at bulkhead 3-81-2 do decrease significantly when the RAMFAN with the water mister attachment is used (Fig. 95).

## 10.2 Lift Test

A lift test was performed to investigate the effects that "back pressure" has on the RAMFAN. This simulated a compartment(s) that was deep in the ship, e.g., a compartment below the water line that needed to be desmoked. The inherent assumption is that there are no overboard discharges readily available (Appendix C describes options for discharging water). To determine the effects of "back pressure," air velocity readings were taken. The change in velocity readings will show the decrease in performance of the fan.

### 10.2.1 Setup and Procedures

The RAMFAN was placed in the well deck. Water was supplied with two sections of 15.3 m (50 ft) 3.8 cm (1.5 in.) hose from FPL 1-70-2. The two sections of 15.3 m (50 ft) 3.8 cm (1.5 in.) discharge hose was lifted 20.6 m (67.5 ft) above the well deck with a crane that was located on the quarterdeck. Air velocity measurements were taken with an anemometer at the suction and discharge ducts. From the velocity readings, the air flow was determined. With the discharge hose raised to 20.6 m (67.5 ft) above the deck, the inlet pressure was varied and velocity measurements taken again. The water supply to the RAMFAN was regulated by adjusting the firemain pressure.

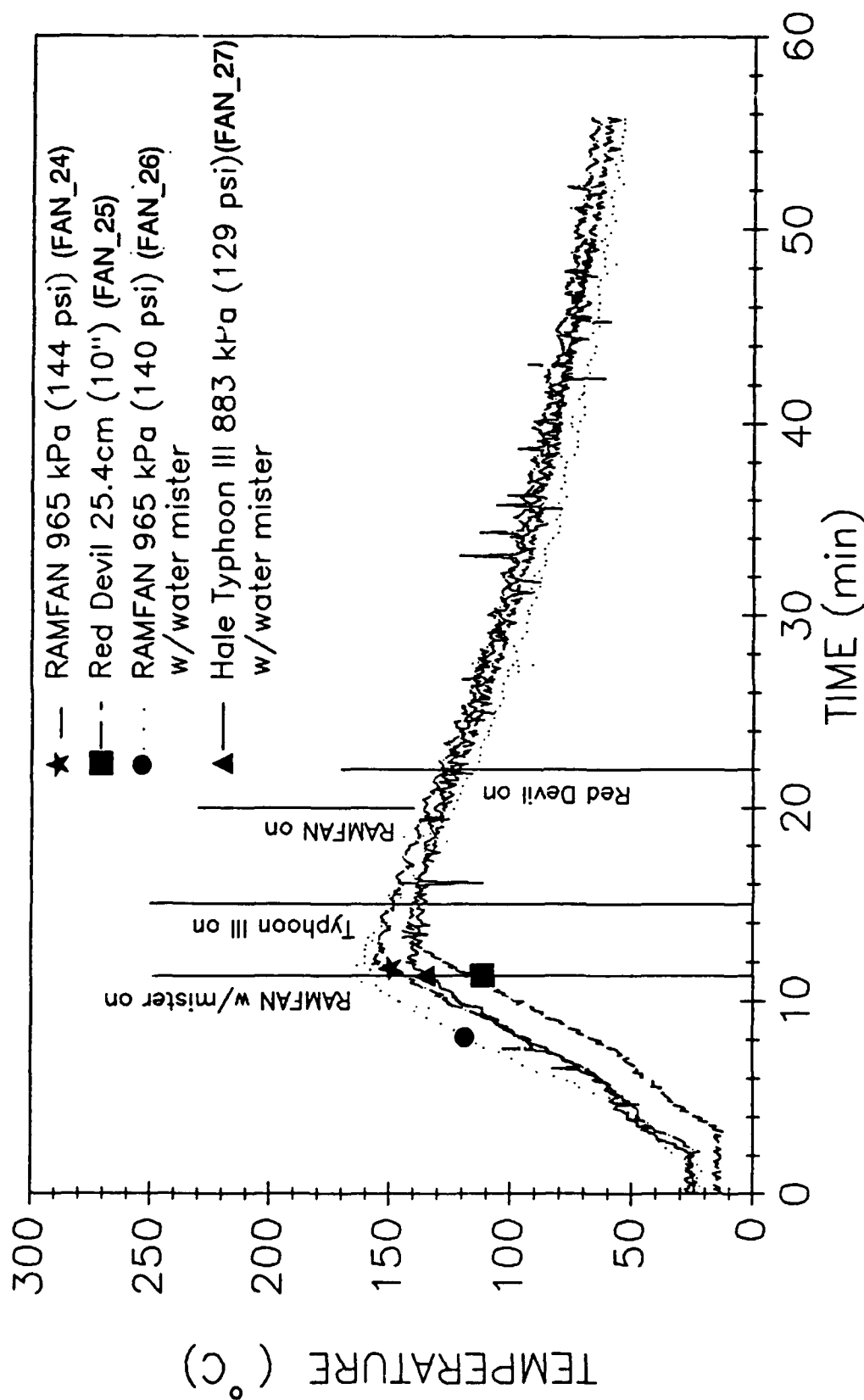


Fig. 94 - Average bulkhead temperatures in BERTHING 2 (3-88-2)

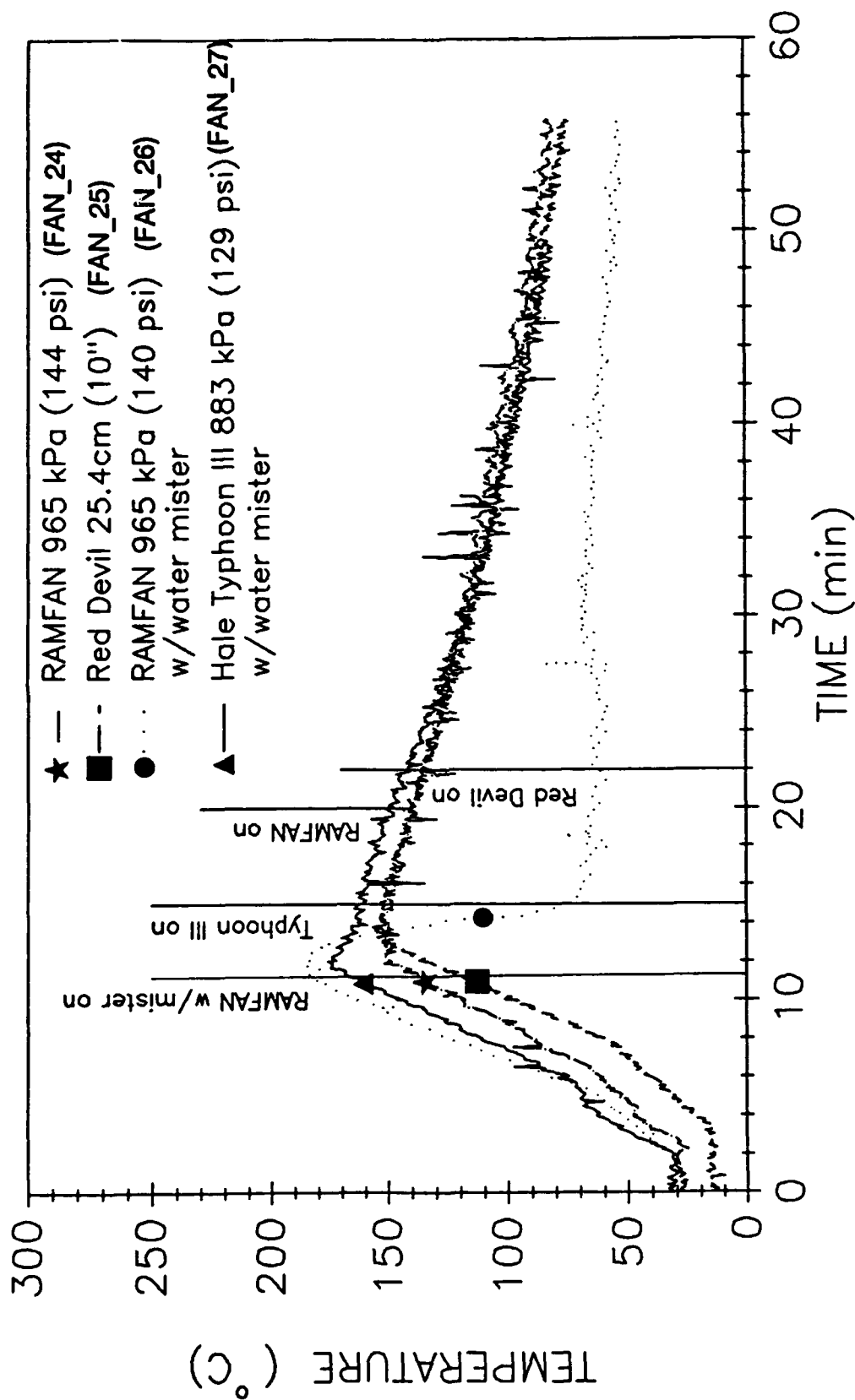


Fig. 95 - Average bulkhead temperatures in BERTHING 2 (3-81-2)

## 10.2.2 Results

The results of the lift test are shown in Table 9. Although the air flows decreased considerably as the back pressure increased, the RAMFAN was still able to deliver a discharge air flow of 9741  $\ell$ pm (344 cfm) when a supply of 365 kPa (53 psi) was used.

Table 9. Lift Test (FAN\_29)

<u>Height above Deck</u>	<u>Fire Main Pressure kPa (psi)</u>	<u>Hydrant Pressure kPa (psi)</u>	<u>RAMFAN Inlet Pressure kPa (psi)</u>	<u>RAMFAN Outlet Pressure kPa (psi)</u>	<u>Air Suction <math>\ell</math>pm (cfm)</u>	<u>Air Discharge <math>\ell</math>pm (cfm)</u>
0 ft	1,006 (146)	985 (143)	965 (140)	110 (16)	55,216 (1,950)	47,854 (1,690)
67.5 ft	1,006 (146)	NR	999 (145)	289 (42)	55,584 (1,963)	13,875 (490)
67.5 ft	703 (102)	696 (101)	723 (105)	262 (38)	41,681 (1,472)	14,583 (515)
67.5 ft	289-310 (42-45)	317 (46)	376 (53)	220 (32)	27,777 (981)	9,741 (344)

NR = not recorded

## 10.3 Heat Stress Test

A high heat stress test was conducted during an ISCC post-flashover burn test in November 1990 [13]. During these tests, the RAMFAN was used to desmoke a compartment. The objective of this test was to determine if the RAMFAN could withstand high heat removal.

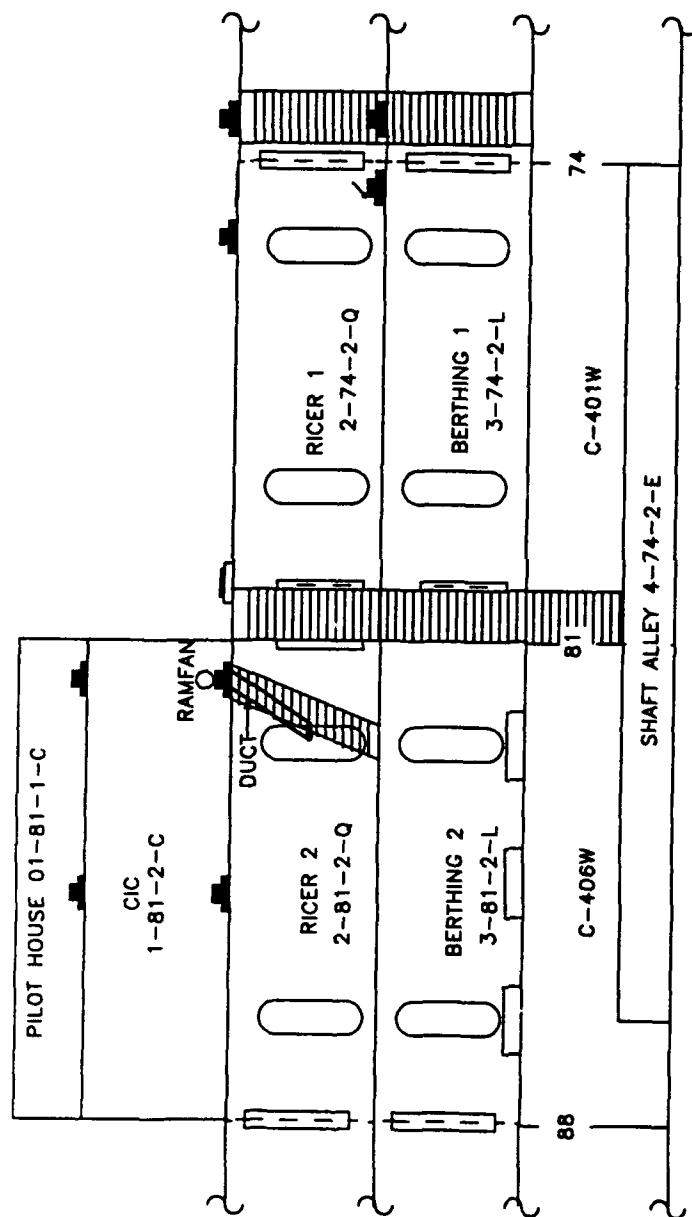
### 10.3.1 Setup and Procedures

All scuttles and doors were secured except QAS 1-81-2 which was open to RICER 2 below for this test. The RAMFAN was placed over this scuttle, with one section of ventilation duct attached to the suction side (Figs. 96 and 97). This hose was positioned on the ladder leading down from QAS 1-81-2 and draped across the compartment to an adjacent ladder. The duct opening was located 1.2 m (4 ft) above the deck of RICER 2; no part of the duct was in contact with the deck.

With the fan in place, a post-flashover fire having an average upper layer temperature on the order of 1000°C (1832°F) was created in BERTHING 2. Ten minutes after ignition, the fan was activated with an inlet water pressure of 965 kPa (140 psi). The diesel spray fire was allowed to burn for ten more minutes before the diesel fuel was secured and the system blowdown.

### 10.3.2 Results

Five minutes after ignition, heavy black smoke was observed in CIC, and intermittent flaming was observed one minute later. Maximum temperatures reached in RICER 2 were 290°C (554°F) as seen in Fig. 98. Figure 98 also shows the temperatures in CIC and the fan inlet temperatures. The maximum temperature at the RAMFAN was 225°C (437°F). A post-test inspection of the RAMFAN revealed that the ventilation duct had burned completely with only the reinforcement wire remaining (Fig. 99). An inspection of the unit revealed no visible effects due to heat. The internal fan area was coated with a heavy layer of greasy soot from the consumed ventilation duct. These combustion products were removed using fresh water, and the fan was restored to operational status.



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Fig. 96 - Configuration of desmoking fan and duct for heat stress test

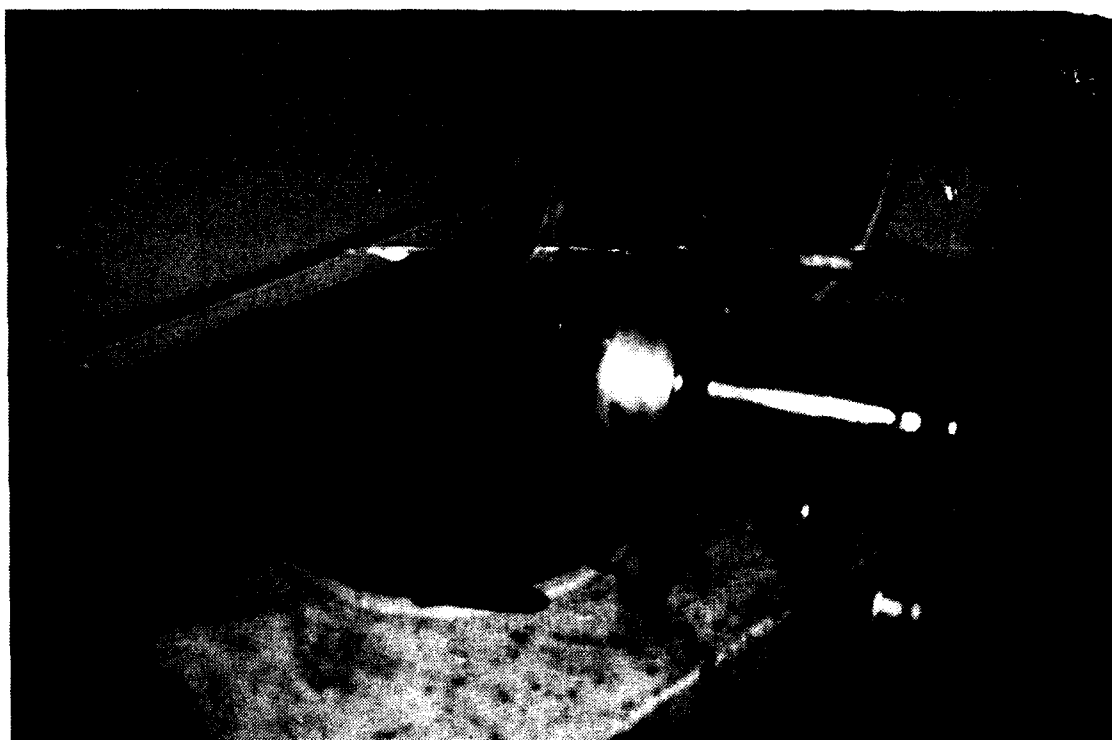


Fig. 97 - RAMFAN located in CIC during high heat stress test

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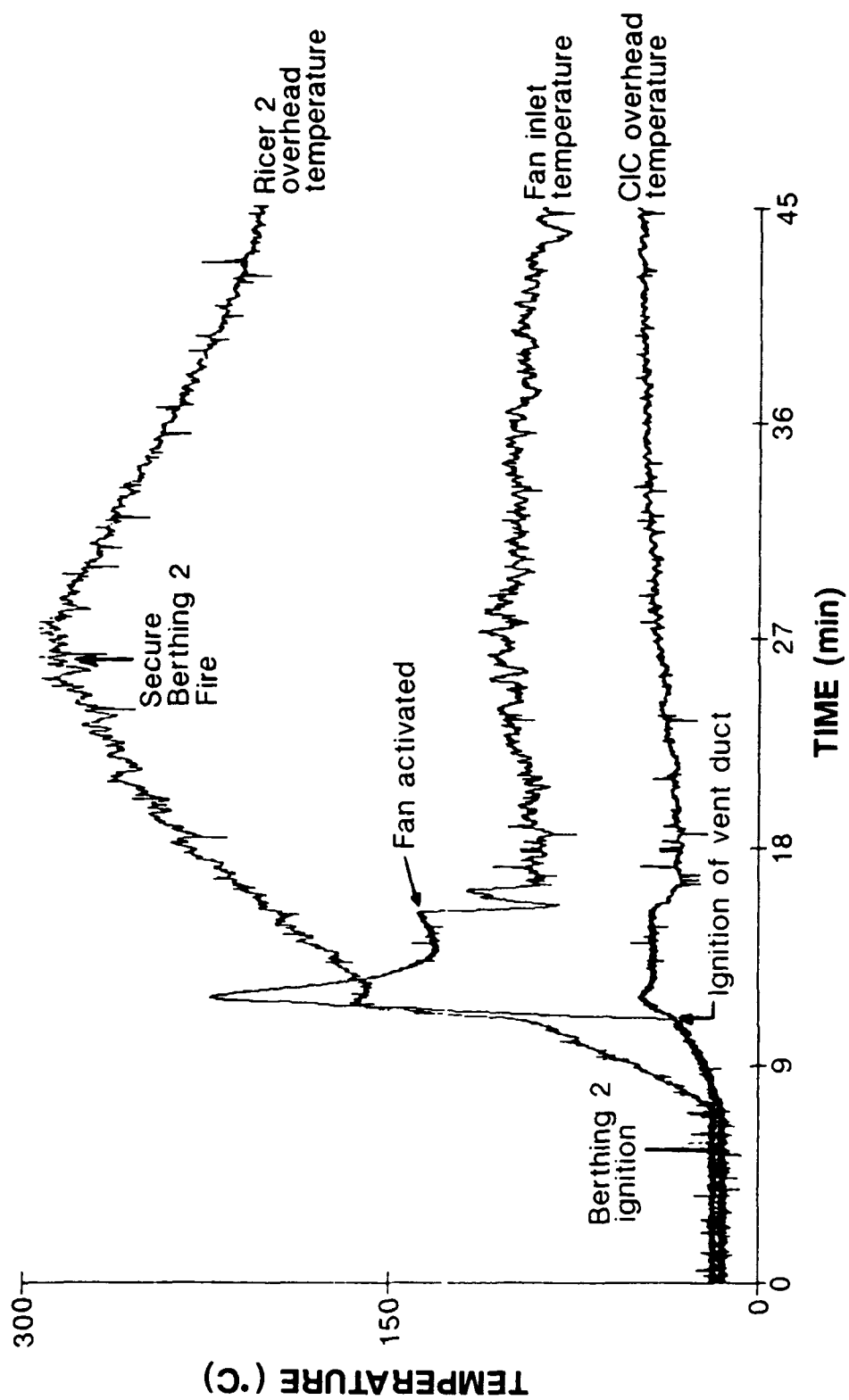


Fig. 98 - Heat stress test





Fig. 99 - Ventilation duct used in the high heat stress test - consumed by flames

Figures 100, 101, and 102 show the temperatures at the inlet duct, the fan inlet, and the duct discharge respectively for the Portable Air Mover test series. The maximum temperature in the ducts occurred during an unmanned dynamic test, FAN\_32, 117°C (243°F). The maximum temperature reached in BERTHING 2 during FAN\_32 was only 531°C (988°F). The temperatures in BERTHING 2 during this test series were only half of the heat stress test. After activation of the fan, the inlet temperature steadied to 120-135°C (248-275°F) for the remainder of the test.

#### 10.4 P-250 Test

A P-250 MOD1 pump was used to supply water to the RAMFAN during a manned dynamic fire test (FAN\_28). The ability to use the P-250 pump with the RAMFAN is important in cases where power to the ship's installed fire pump is lost.

##### 10.4.1 Setup and Procedures

The P-250 was located on the stern gate on the third deck aft. Two sections of 15.3 m (50 ft) hose with a rise of 2 decks were connected to the hydrant at 1-96-2 on the main deck. This was connected to FPL 1-92-2 with 6.09 m (20 ft) of 8.9 cm (3.5 in.) CuNi piping. The CuNi piping led to the temporary hydrant at 1-70-2. From the hydrant, two sections of 6.4 cm (2.5 in.) hose were used to supply the RAMFAN. The hose was attached to the RAMFAN with a 6.4 cm x 3.8 cm (2.5 in. x 1.5 in.) reducer. The 6.4 cm (2.5 in.) discharge hose was attached to the fan with another 6.4 cm x 3.8 cm (2.5 in. x 1.5 in.) reducer. The hose was allowed to discharge onto the third deck.

The fire test, FAN\_24, was then conducted in the same manner as the other large scale fire tests. Water to the RAMFAN was turned on and off at FPL 1-70-2.

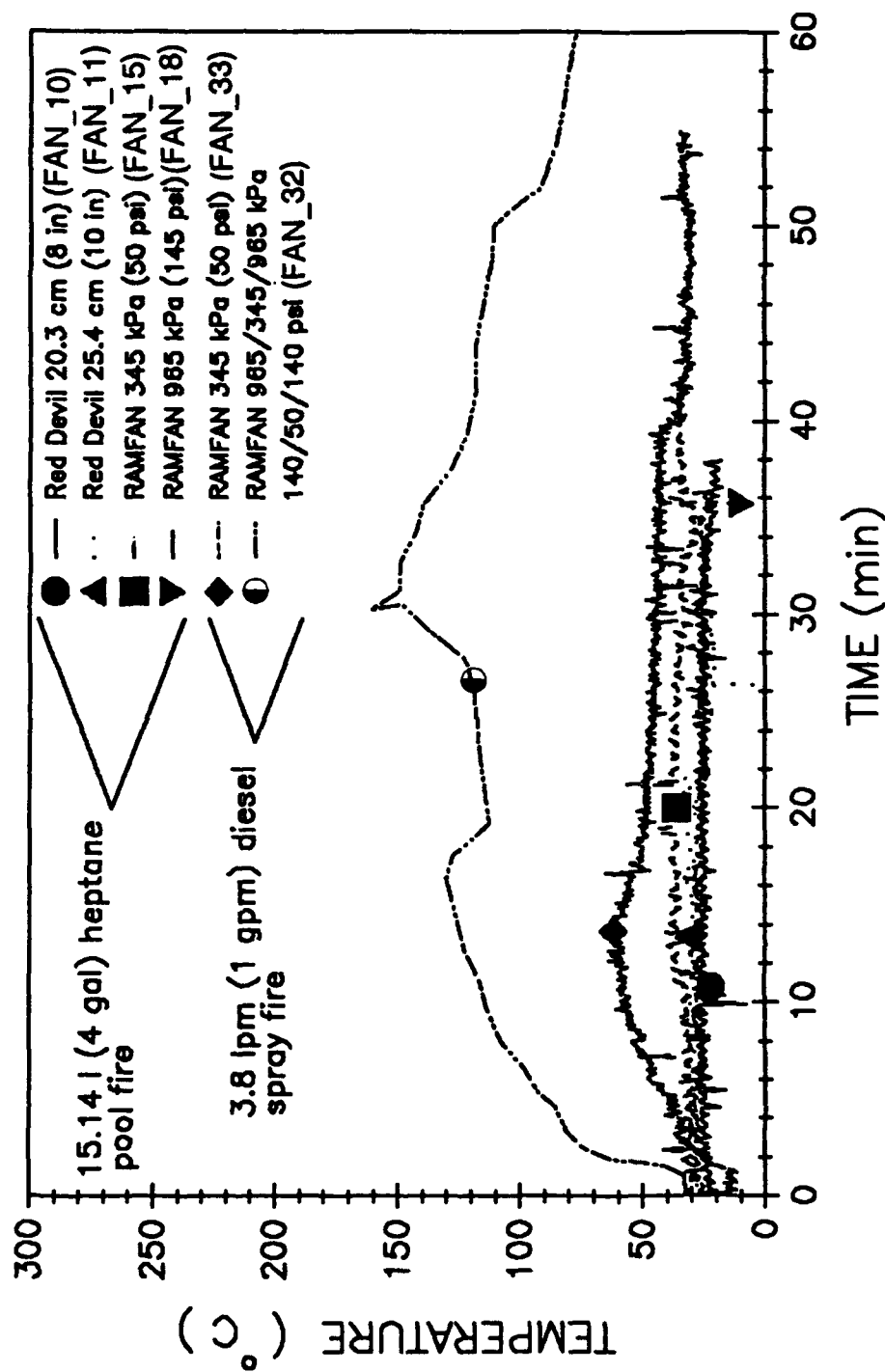


Fig. 100 - Inlet duct temperature after fan is activated

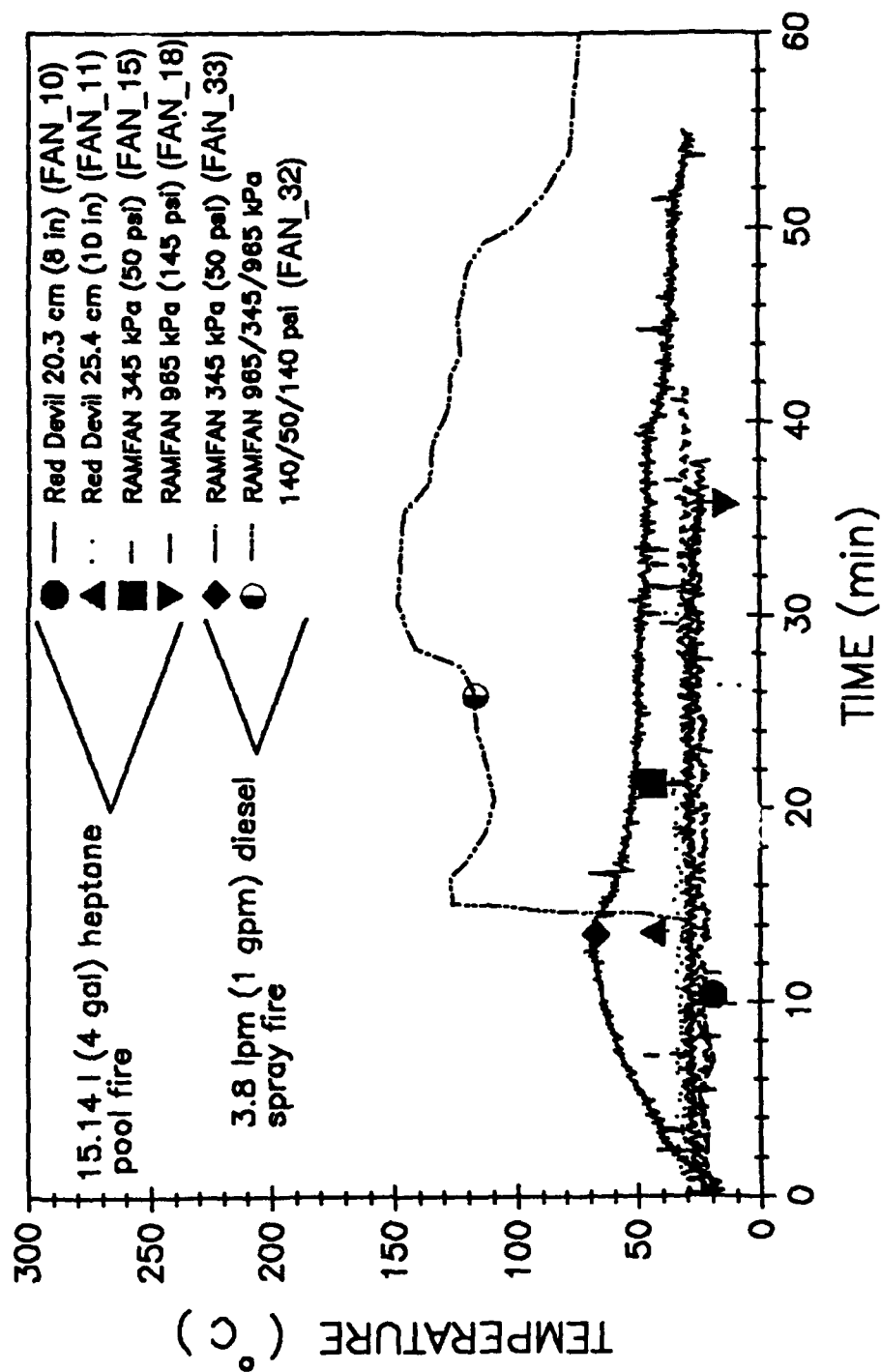


Fig. 101 - Inlet fan temperature after fan is activated

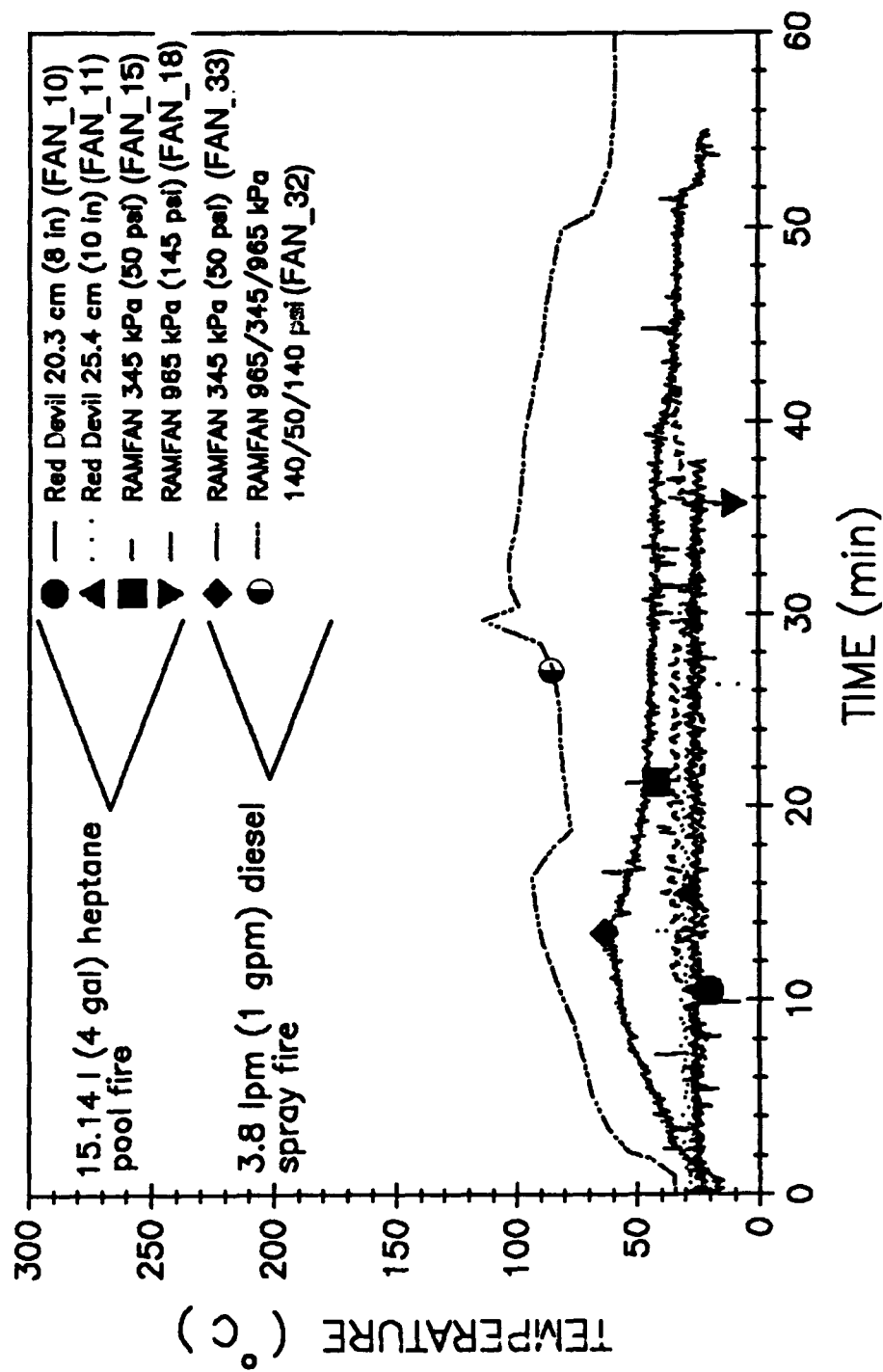


Fig. 102 - Discharge duct temperature after fan is activated

#### 10.4.2 Results

Figures 86 and 103 show the percent transmittance in RICER 1 of two WMF tests. In FAN\_28, the WMF was supplied by the P-250. In comparing these two tests, the P-250 did not affect the performance of the RAMFAN. The inlet pressures to the fan averaged 862 kPa (125 psi) which was slightly less than the average inlet pressure of the fans run at higher fire main pressures (965 kPa (140 psi)).

### 10.5 Brackish Water Test

A pump supplying brackish water to the inlet of the RAMFAN was allowed to run continuously for 48 hours to see if brackish water would have any adverse effects on the RAMFAN.

#### 10.5.1 Setup and Procedures

The P-250 was used to supply the RAMFAN with brackish water via one section of 15.3 m (50 ft) hose. The discharge from the RAMFAN was released overboard via one section of 15.3 m (50 ft) hose. The RAMFAN was allowed to run for 48 hours without interruption.

#### 10.5.2 Results

After 48 hours, the RAMFAN was disassembled and examined for any damage. No visible damage, such as pitting or corrosion, was seen on the blades or the fan housing of the RAMFAN. After this test, the fan was rinsed off with fresh water.

### 10.6 Conclusions of Supplementary Tests

The WMF with the integral spray feature appears to have the potential for being an effective tool for gaining access to hot compartments. As seen in Fig. 92, the temperatures decreased rapidly when compared to Fig. 90. Not only were the

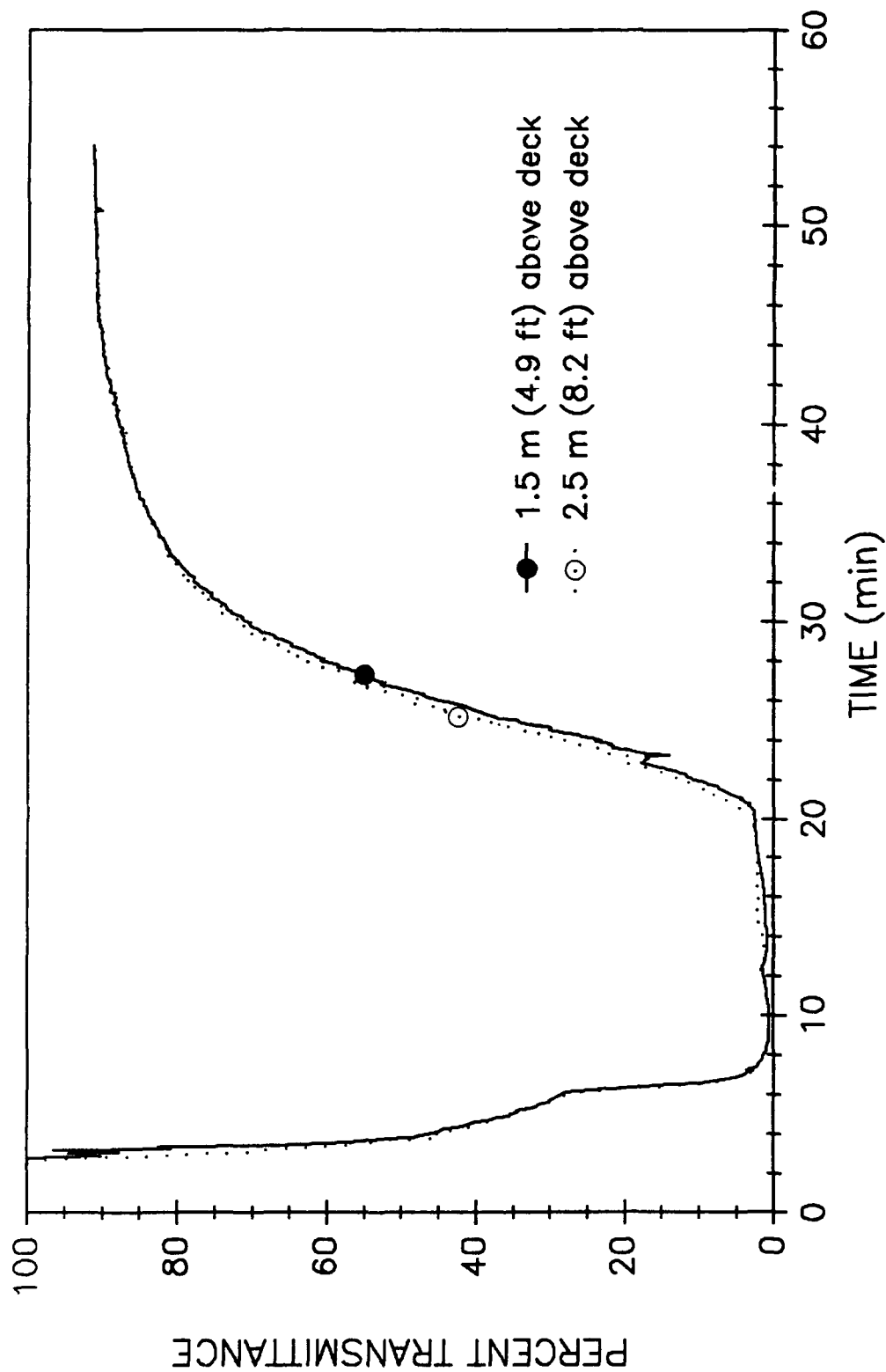


Fig. 103 - Percent transmittance in RICER 1 during FAN\_24  
using RAMFAN 992 kPa (144 psi)

compartment air temperatures decreased, but the opposite bulkhead temperatures from the WMF decreased as well. The WMF was able to extinguish the residual flames in the compartment which suggests the possibility of it being used as a tool for indirect firefighting.

In addition to the RAMFAN, the Hale Typhoon III was also tested for its water misting capabilities. As seen in Figs. 92 and 93, the temperature did not decrease as rapidly as the temperatures in the RAMFAN test.

The RAMFAN's ability to desmoke compartments in a deep ship are not lost. However, back-pressure does limit the fan's capacity to desmoke an area.

During the heat stress test, the WMF was able to sustain temperatures up to 225°C (437°F) without damage to the fan unit. The ducts had burned completely, leaving only the reinforcement wire. This may be an effective tool during very hot fires.

The P-250 test and the brackish water test demonstrated the WMF's capability to be used with the Navy portable fire pump and with brackish water. The performance of the RAMFAN was not impeded by the P-250 or by the brackish water.

## **11.0 SUMMARY OF CONCLUSIONS**

### **11.1 Tests**

1. In all situations, the RAMFAN at high pressures was the most effective device for desmoking an area.
2. The RAMFAN can be used to desmoke hot areas without damage to the fan. However, the ducts may fail when exposed to high heat.



3. The RAMFAN can be used to desmoke areas in deep ships even though the back-pressure from the discharge hose will decrease the fan's capacity.
4. The integral water spray feature demonstrated during this test series appears to have the potential for being an effective tool for gaining access to hot compartments.
5. The Red Devil with the 25.4 cm (10 in.) duct is comparable to the RAMFAN at low pressures (365 kPa (50 psi)).
6. Increasing the duct size on the Red Devil from 20.3 cm (8 in.) to 25.4 cm (10 in.) resulted in improved desmoking performance.
7. Given ready access to a water source and overboard discharge, the setup time of the RAMFAN was judged to be equal to the time to rig the Red Devil fan.
8. Make-up air to the compartment being desmoked is essential. Maintaining positive control of air improves the efficiency.
9. Based on the limited data, the location of the make-up air does not appear to be critical.

## 11.2 Equipment

1. The rims on the RAMFAN ducts deteriorated after limited use.
2. As a result of high water pressures or pressure surges, there is a tendency for the swivel connection on the RAMFAN to fall and cause the fan unit to tip.

3. The suction and discharge ducting of the RAMFAN could not easily be differentiated.
4. The static ground line had a tendency to unclip because it was so short.

### **11.3 Doctrine, Tactics and Procedure**

1. Both the supply and discharge hoses to the RAMFAN need to be kept free of kinks.
2. The RAMFAN needs to be supervised in case water pressures would cause the unit to tip over.
3. The P-250 can be used to supply water to the RAMFAN.
4. The use of smoke curtains in conjunction with the RAMFAN is effective.
5. Smoke curtain throttling is an effective technique.

## **12.0 RECOMMENDATIONS**

Based on the findings and conclusions as outlined in this report, ships should be equipped with the RAMFAN to supplement the Red Devil. Training should be provided on the proper use of the WMF to desmoke areas. The following are some specific recommendations that evolved from this test series.

### **12.1 Tests**

1. Further investigation is needed in the use of the WMF water mister in the applications of cooling and extinguishing. This might include tests to determine the optimum mister flow rates and tactics.

2. Further testing should be performed to investigate the fresh make-up air to the compartment being desmoked.

## **12.2 Equipment**

1. The Red Devil should be equipped with an adapter so that the 25.4 cm (10 in.) ducts can be employed.
2. The rims on the RAMFAN ducts should be improved so that they do not degrade easily.
3. The static ground line on the RAMFAN should be lengthened.
4. The swivel hose connection on the RAMFAN needs to be improved so it does not cause the fan to tip over.
5. An improved designation on the suction and exhaust ducts of the RAMFAN is needed so they can easily be discerned. Alternatively, the suction and discharge ducts should be the same design.
6. The strainer on the inlet hose connection to the RAMFAN should remain to prohibit any possible debris from entering the fan unit.
7. Since the water-mister feature appears to be an effective improvement, new orders for the RAMFAN should include equipment to readily adapt an integral spray nozzle (e.g., provide the valve and outlet for the nozzle).

## **12.3 Doctrine, Tactics, and Procedures**

1. Doctrine, tactics, and procedures should be provided in the use of the RAMFAN.

2. Tactics and procedures should be provided in the use of smoke curtains in conjunction with desmoking fans.

Appendix C provides draft example guidance for the development of tactics and procedures for the WMF.

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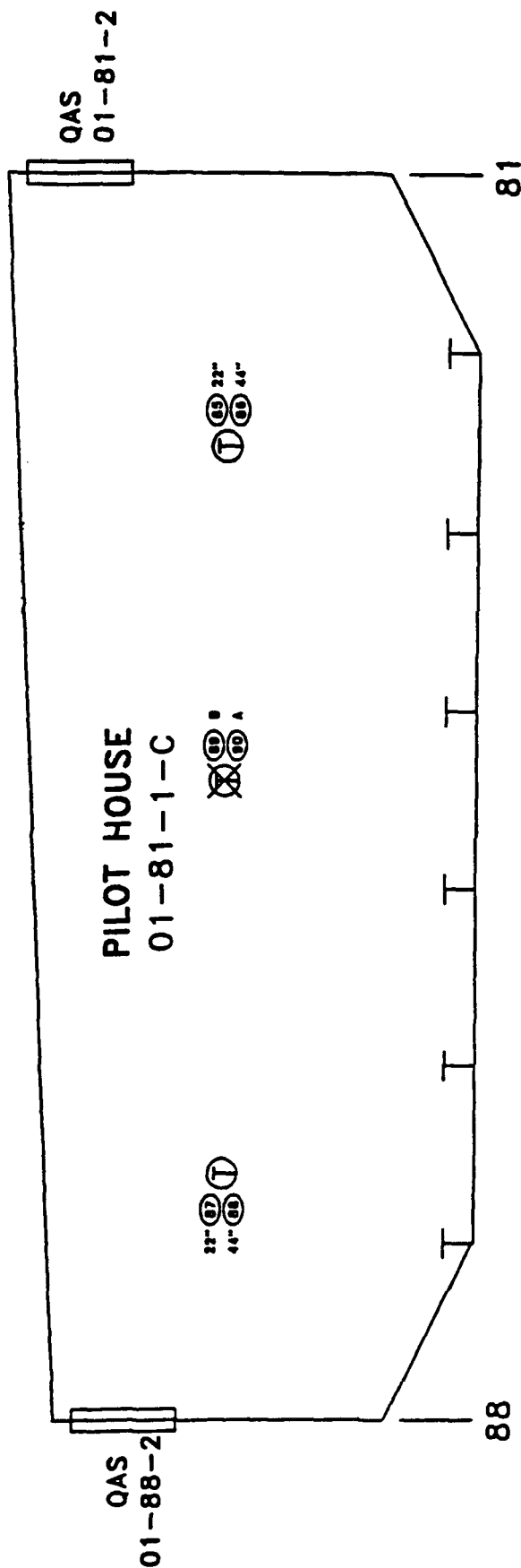
## APPENDIX A

### Location of Instruments

## INSTRUMENTATION KEY

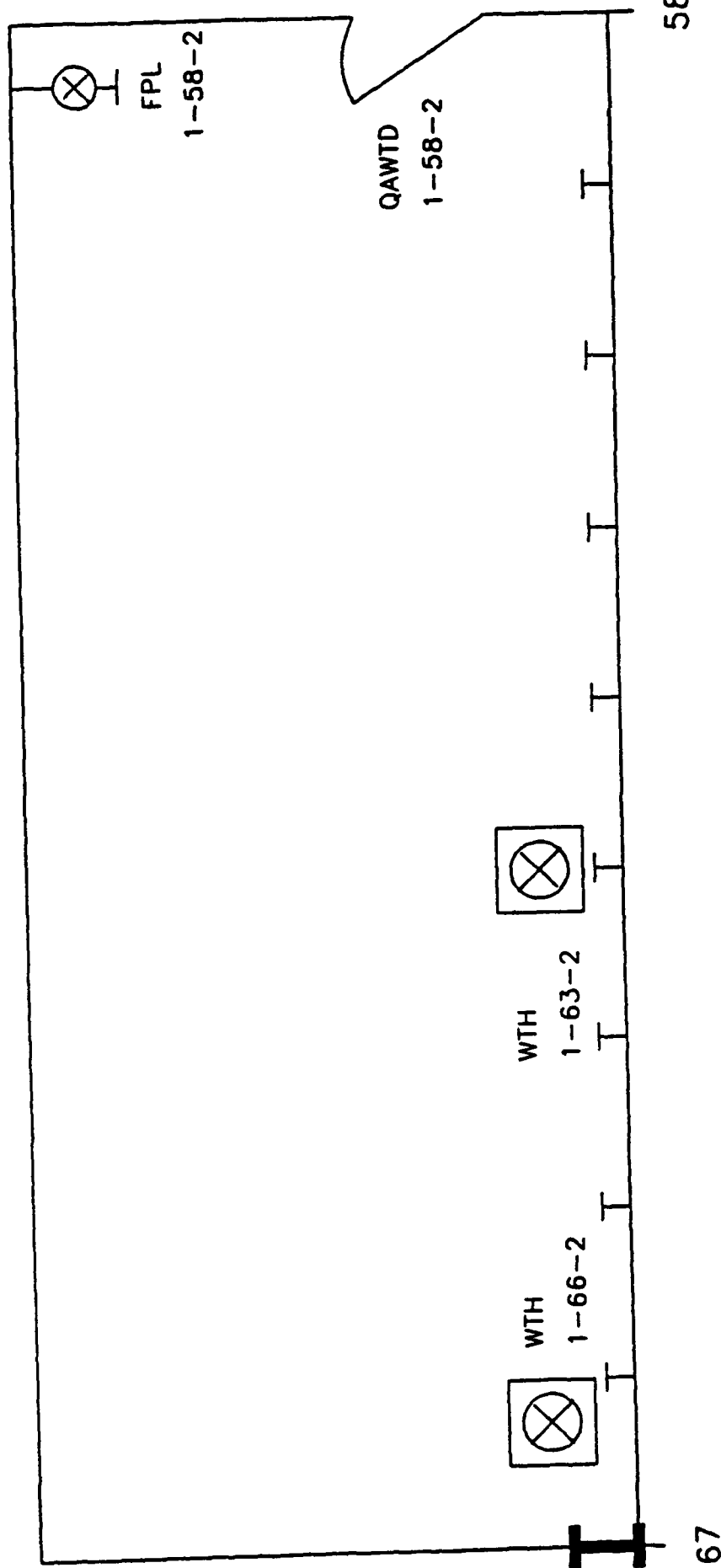
- ⊙ T Thermocouple tree
- ⊗ Deck thermocouple
- ODM Optical density meter
- ⊙ G Gas line
- ⊙ V# → Camera
- ⊙ A# Audio
- ⊙ IR# → Infra red GE lens
- F Ultrasonic flow meter
- ⊙ R Radiometer
- ⊙ C Calorimeter
- ⊙ P Differential pressure





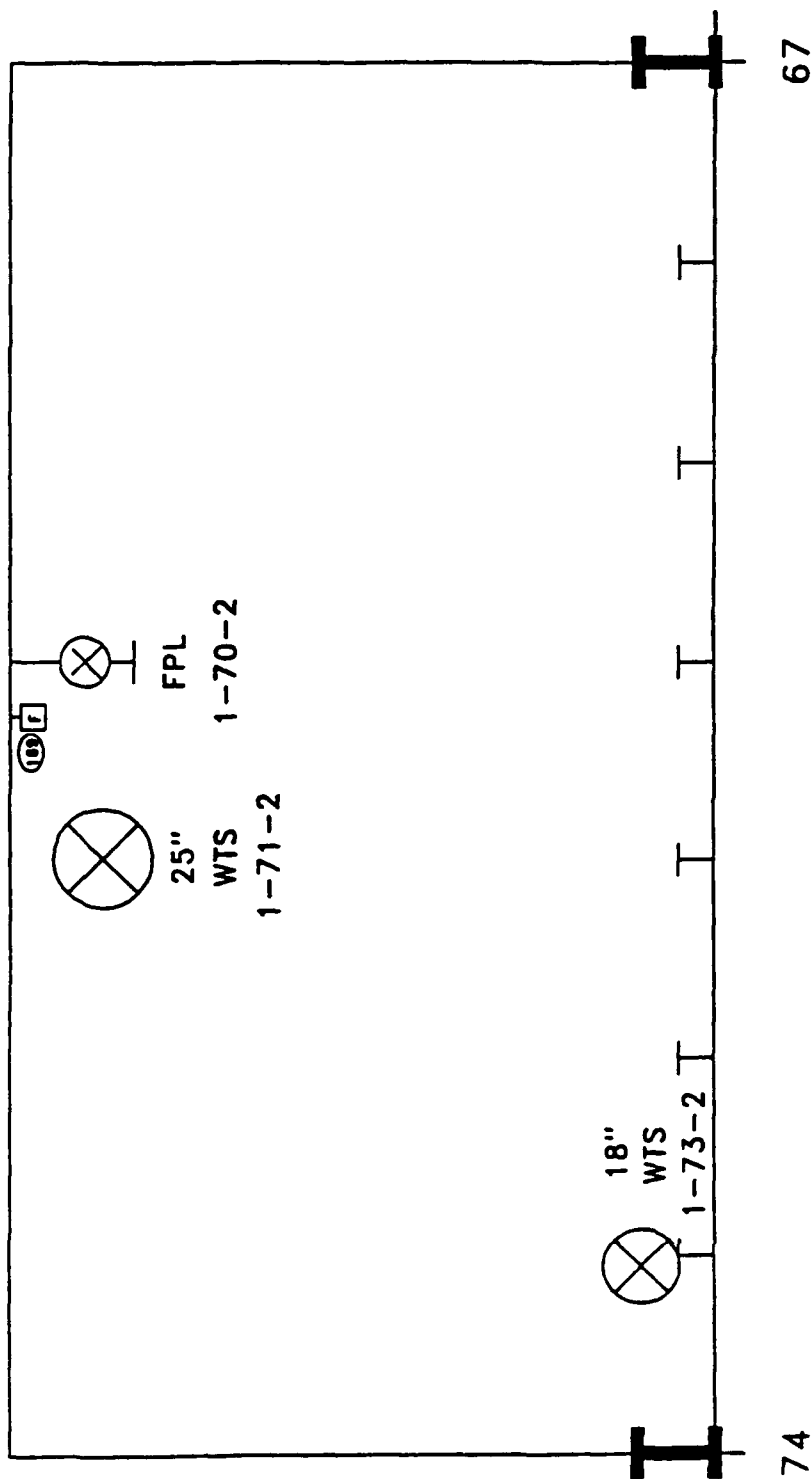
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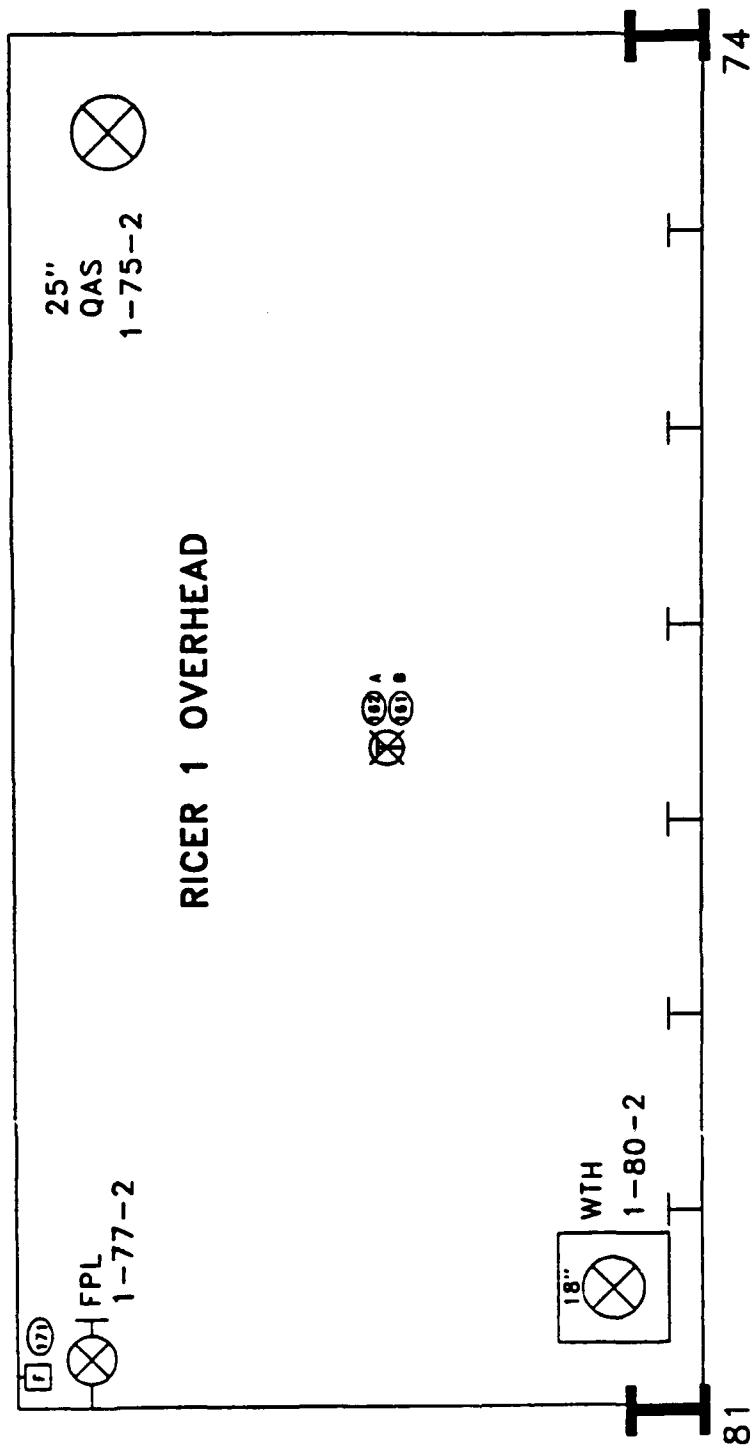
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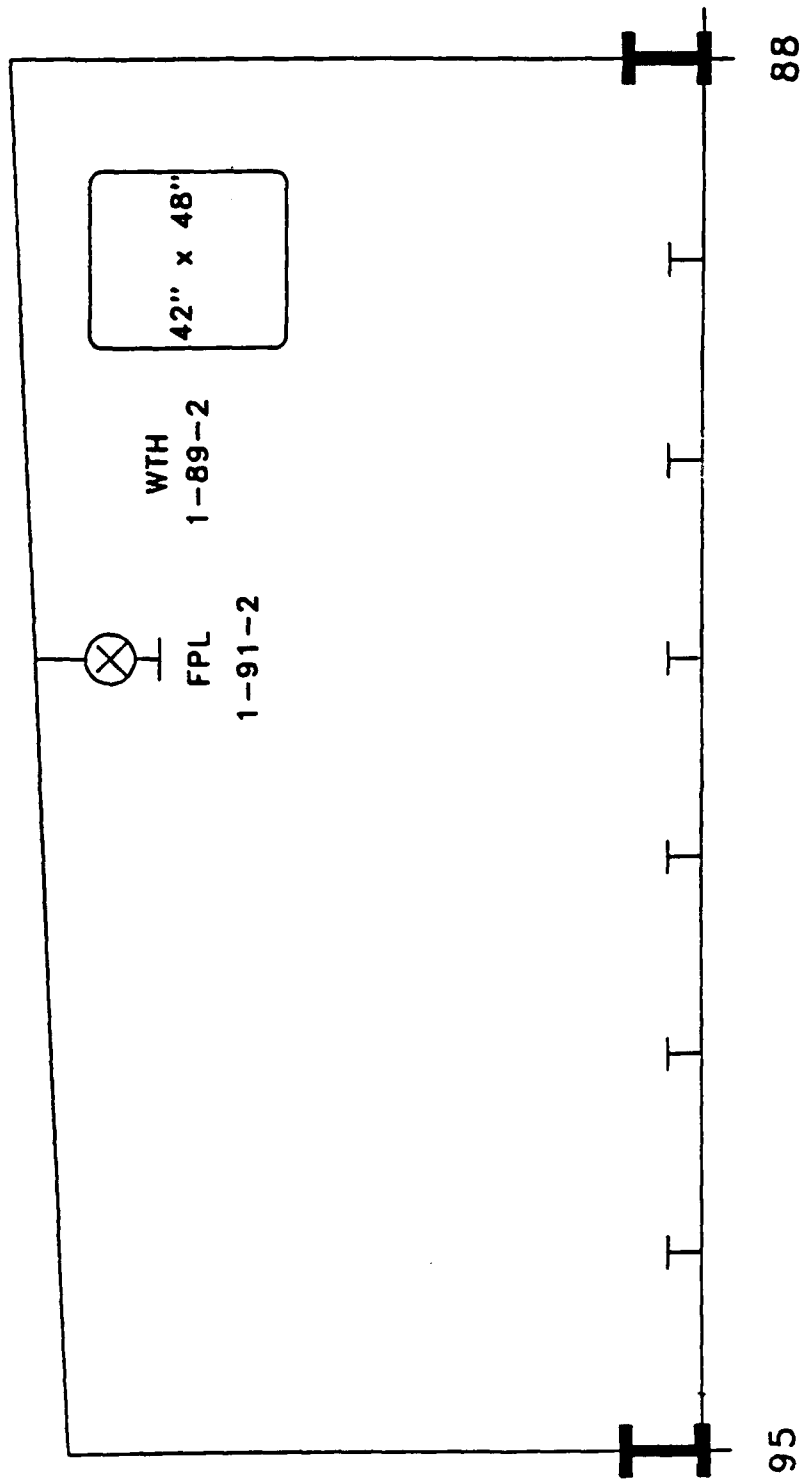


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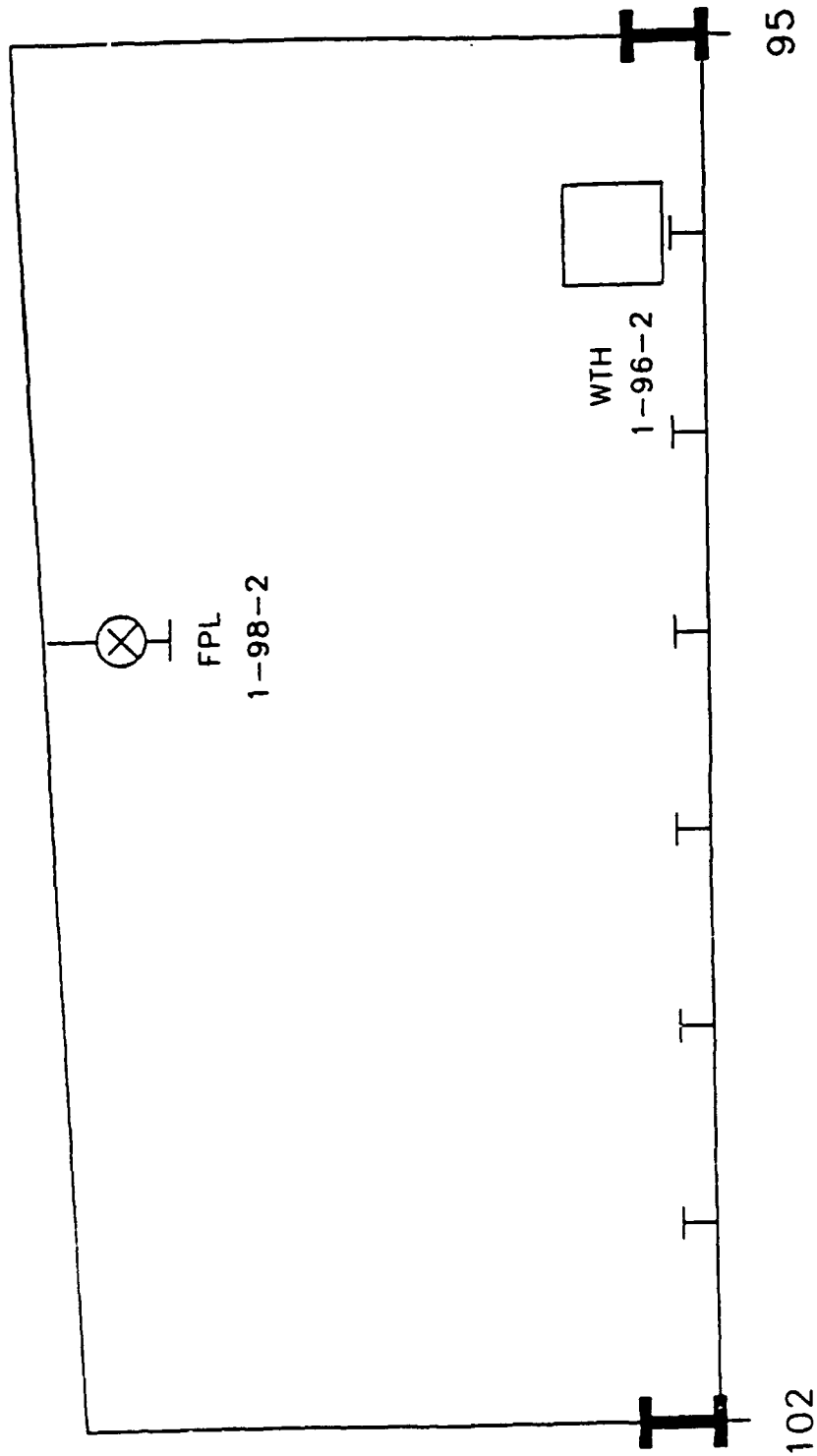




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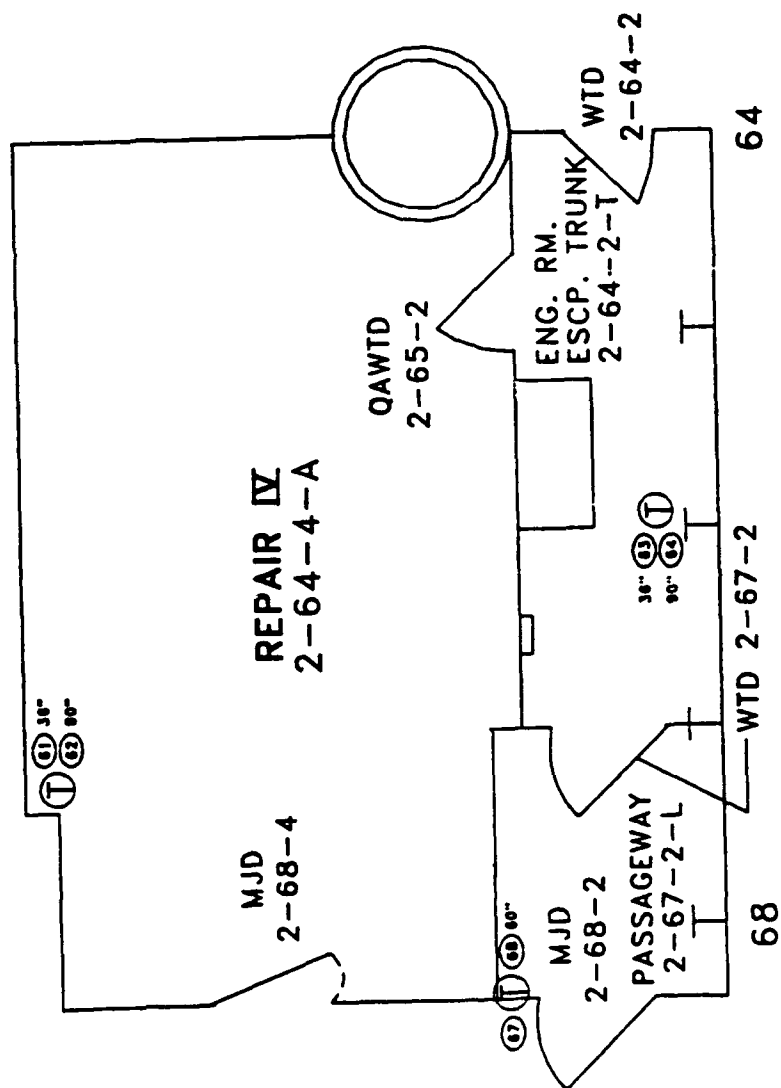
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BY: KJ BACK	FILE: MD102 D.3

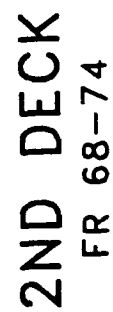


## 2ND DECK

FR 64-68

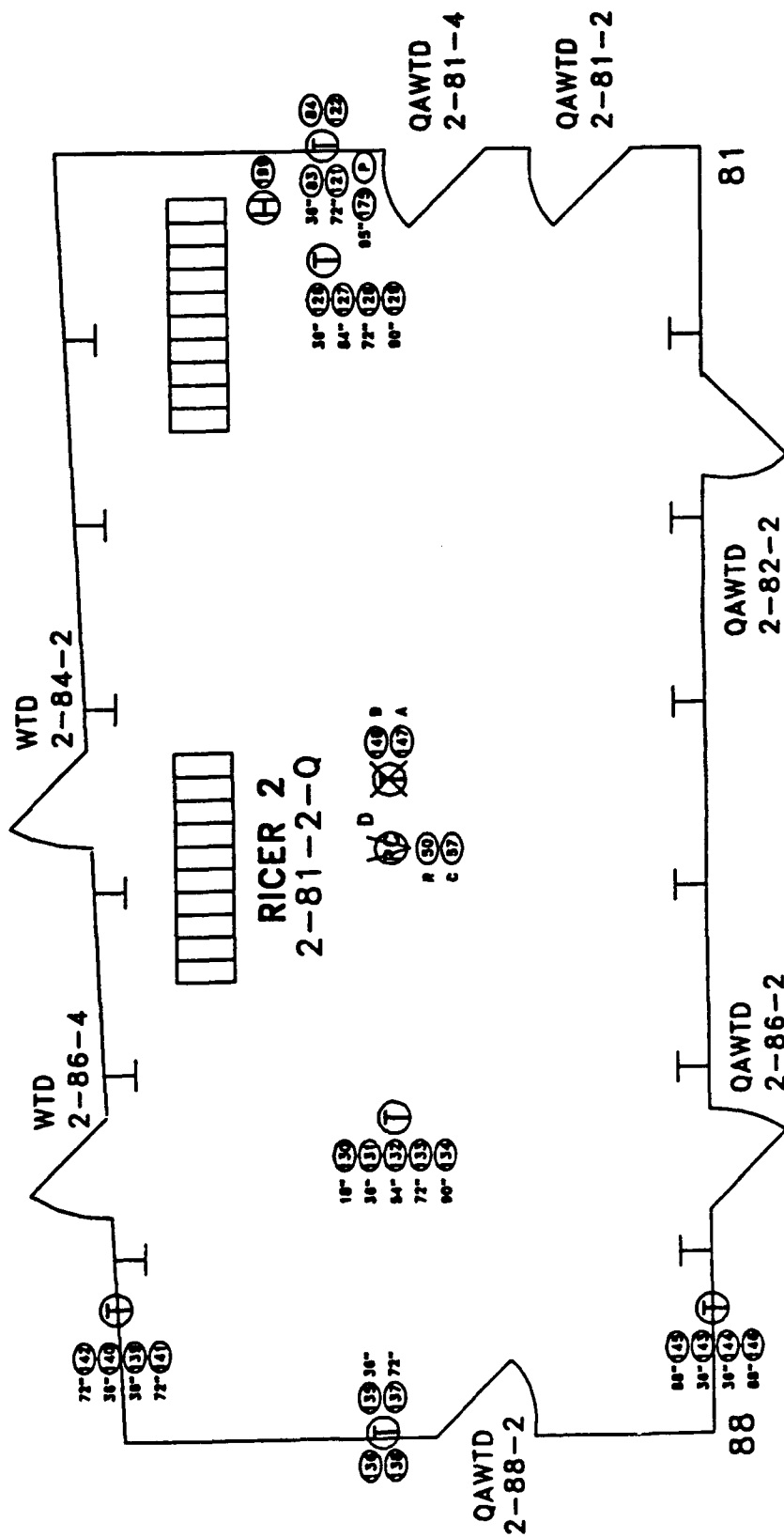
DATE: 1/11/90	REVISED: 11/1/90
BY: KJ BACK	FILE: D208 D:1





A-11

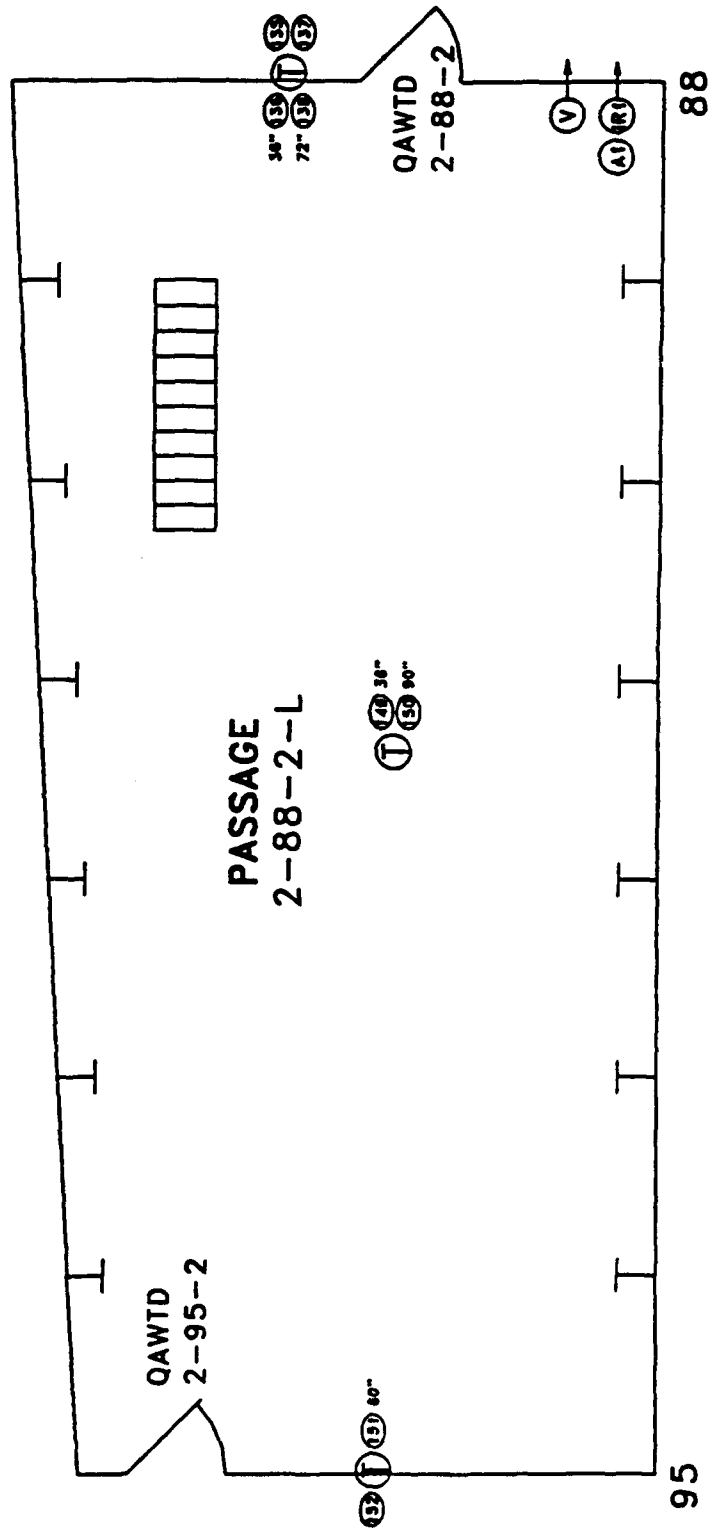
A-12

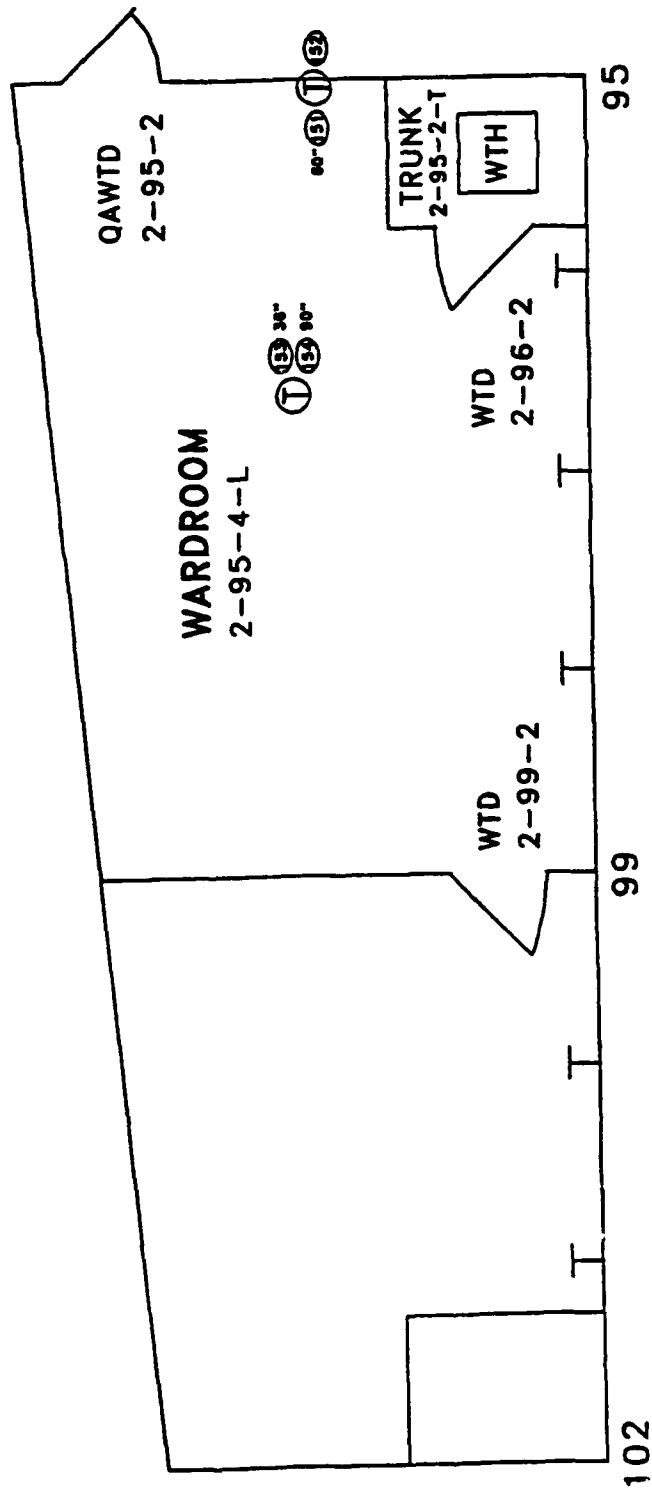


# 2ND DECK

FR 81-88

DATE: 1/11/80	REVISED: 7/15/81
BY: KJ BAC	FILE: D288 D-1

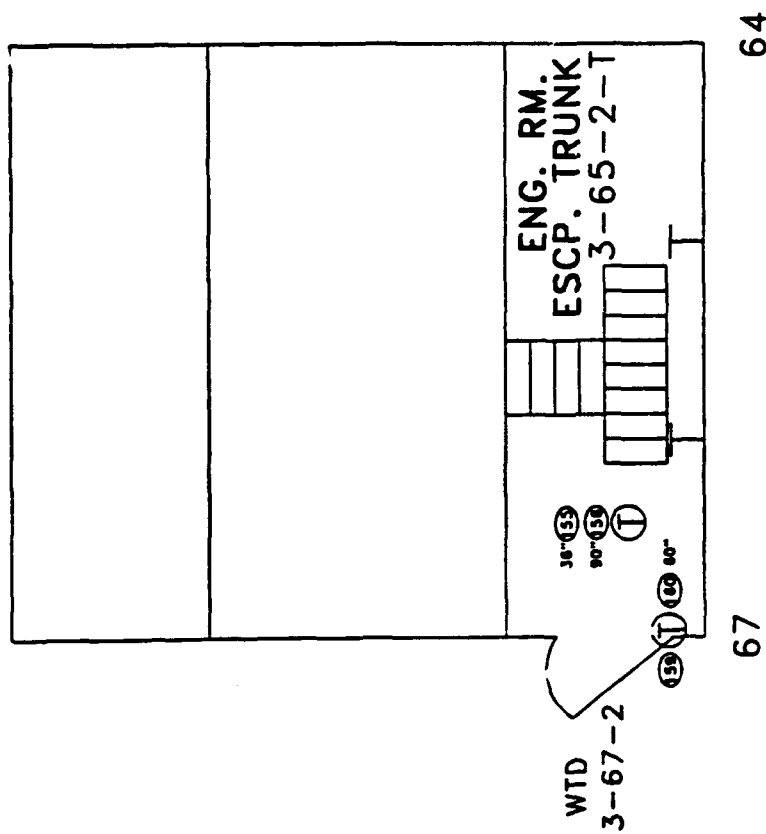




## 2ND DECK

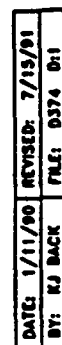
FR 95-102

DATE: 1/11/90	REVISED: 7/19/91
BY: KJ BACK	FILE: 02102 011

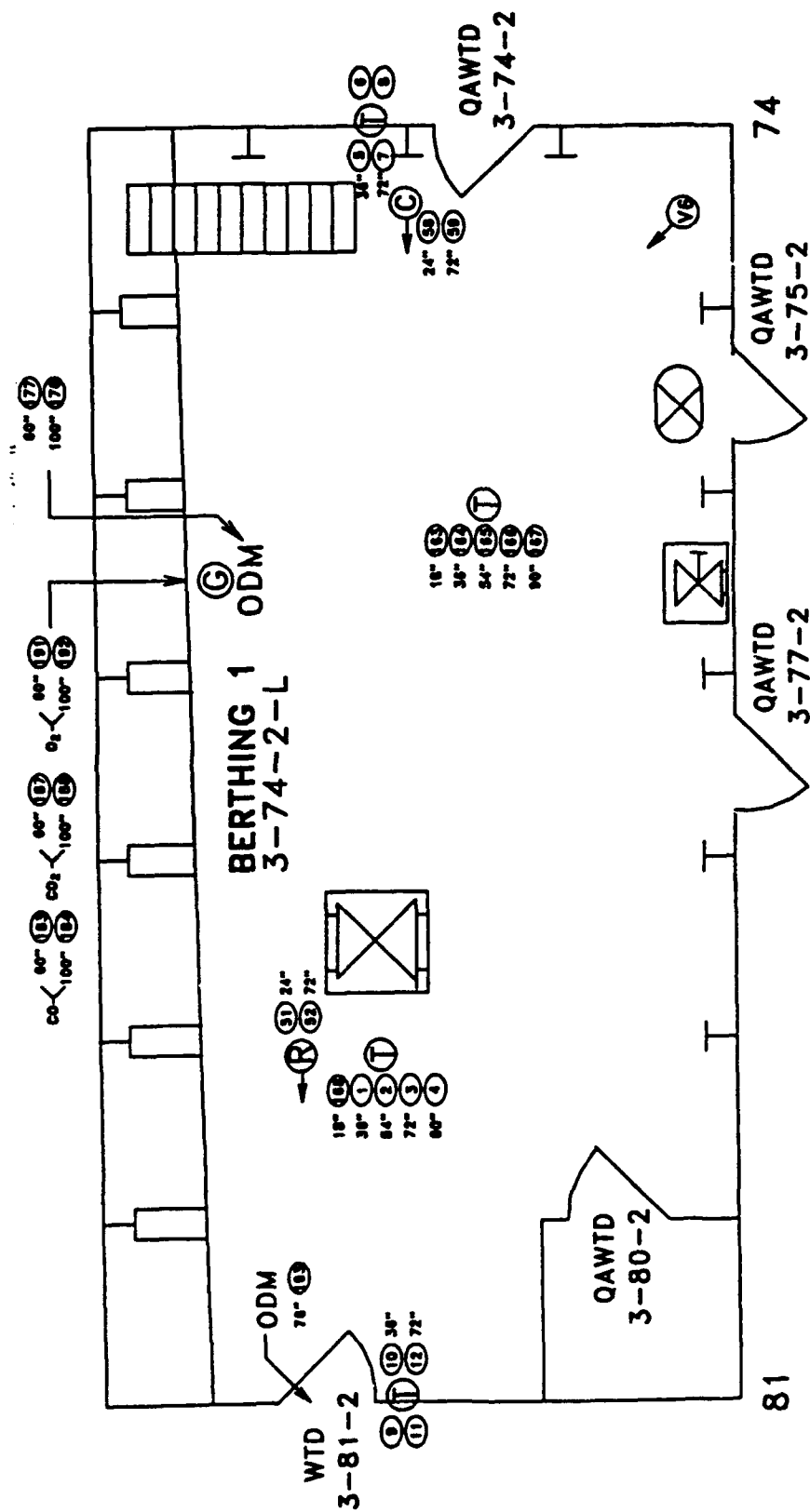


# 3RD DECK FR 64-67

DATE: 1/11/90	REVISED: 11/1/90
BY: NJ BACK	FILE: D367 D-1



FR 67-74



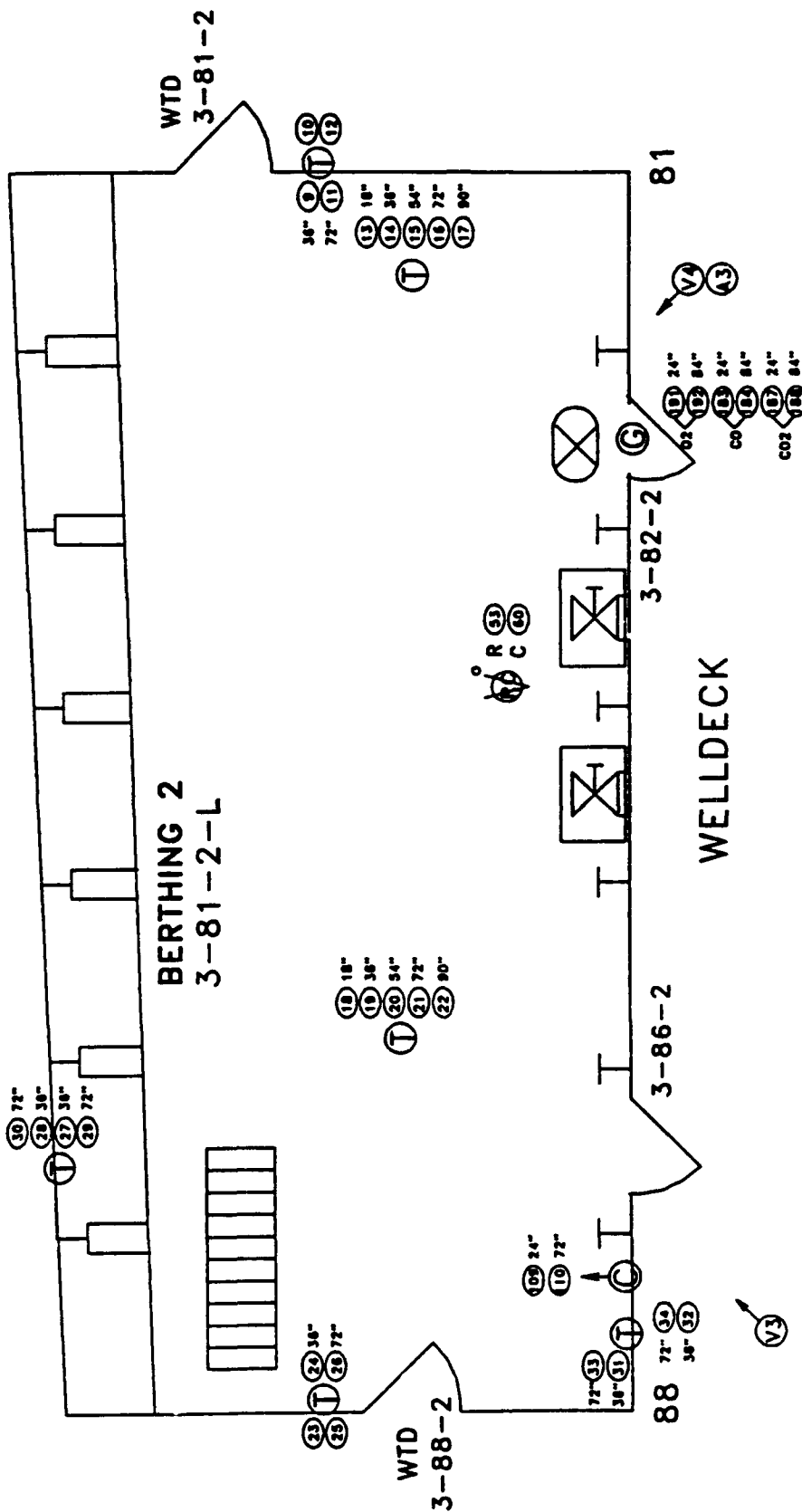
# 3RD DECK

FR 74-81

DATE: 1/11/90	REVISED: 11/1/90
BY: KJ BAC	FILE: 0301 D11



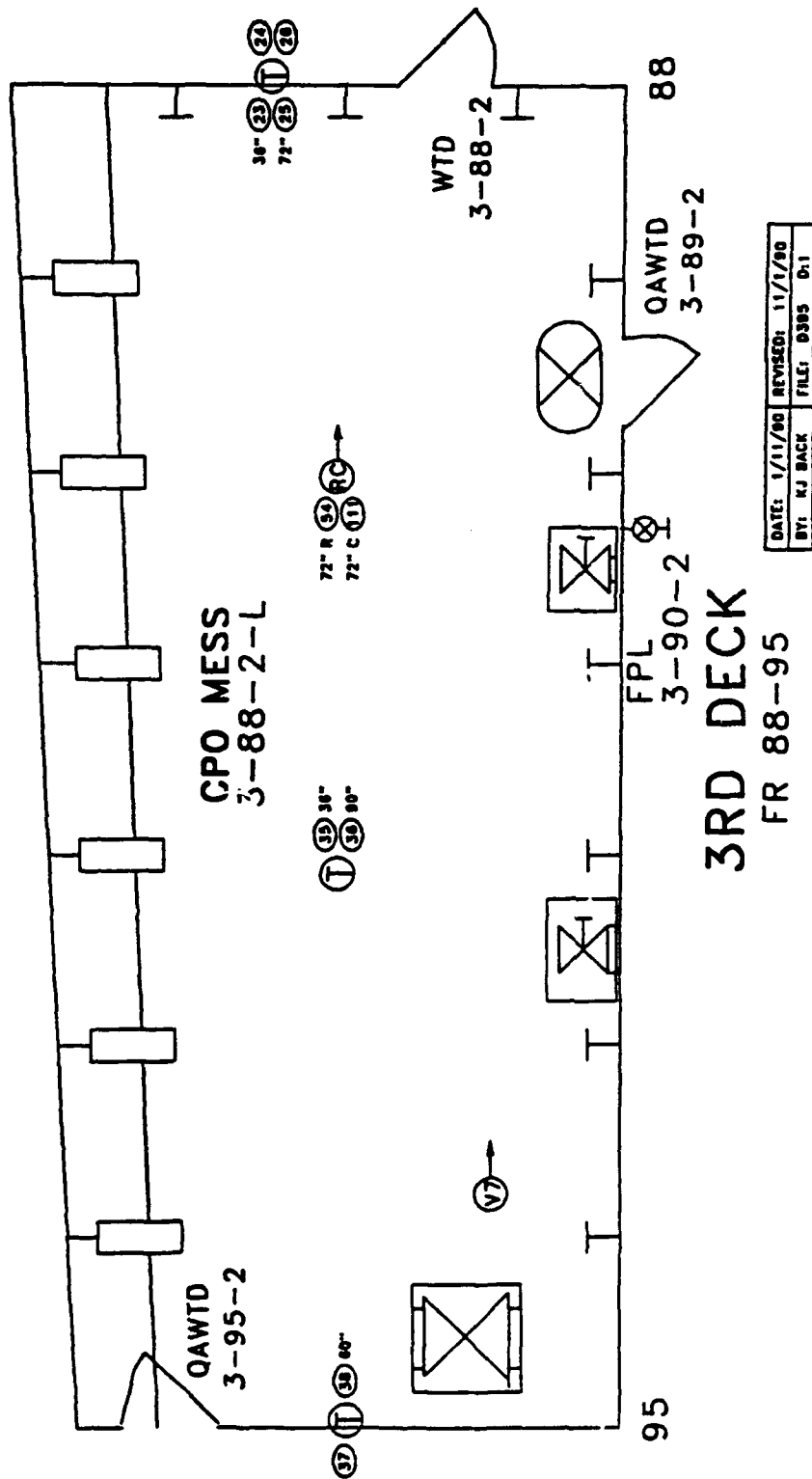
⑦ FROM ISLAND

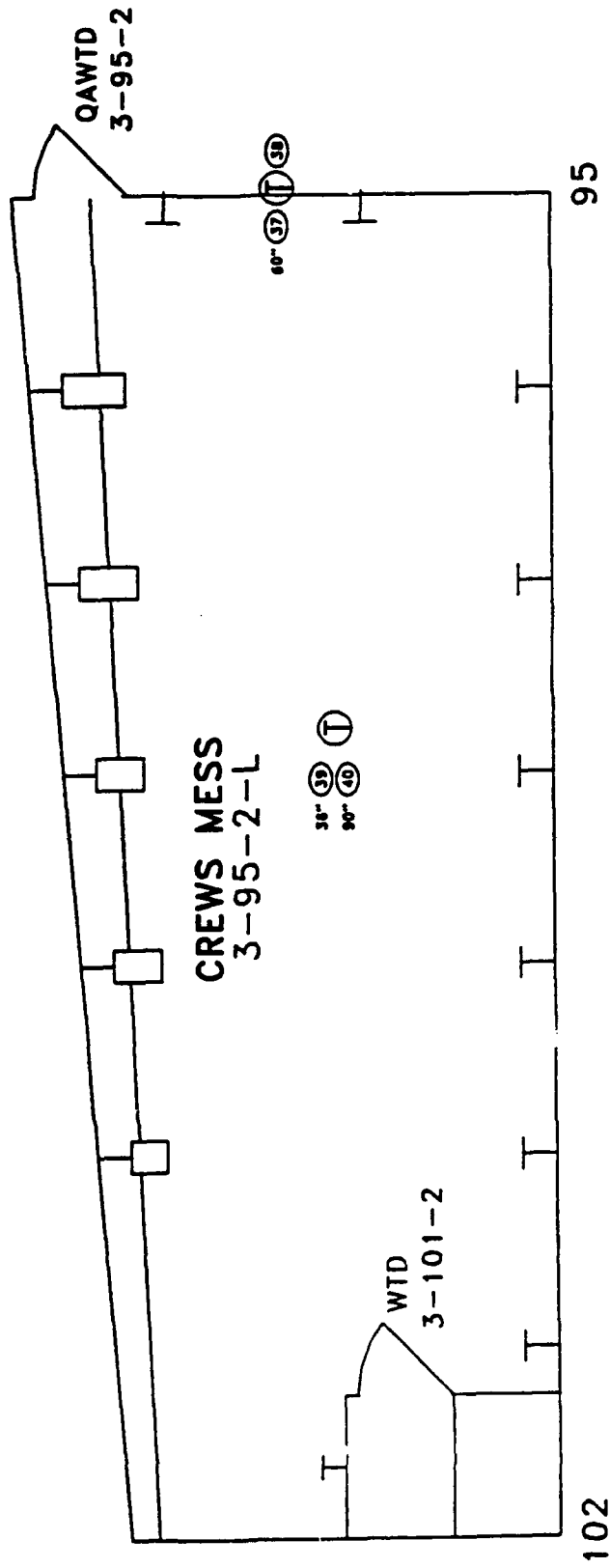


3RD DECK

BH 81-88

DATE: 1/11/80	REVISED: 7/19/81
BY: MJ BACH	FILE: D388A D:1





# 3RD DECK FR 95-102

DATE: 1/11/90	REVISED: 11/1/90
BY: KJ BACK	FILE: D3102 D:1

**APPENDIX B**

**Data for Selected Channels**

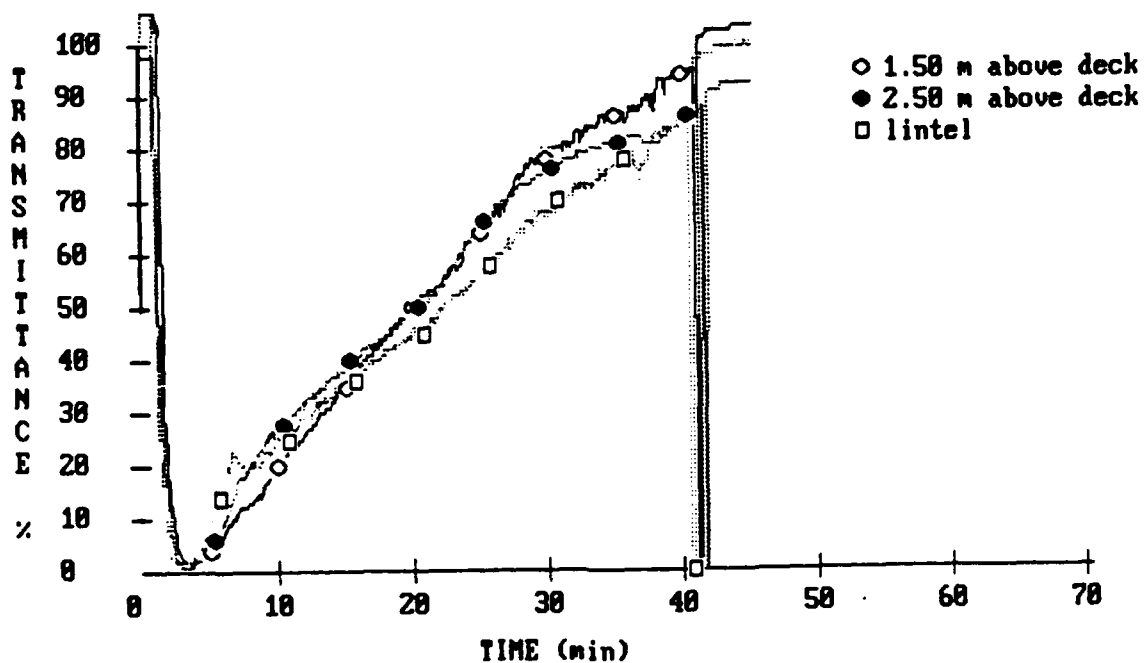


Fig. B-1- Smoke in BERTHING 1 (3-76-2) during Test # 2

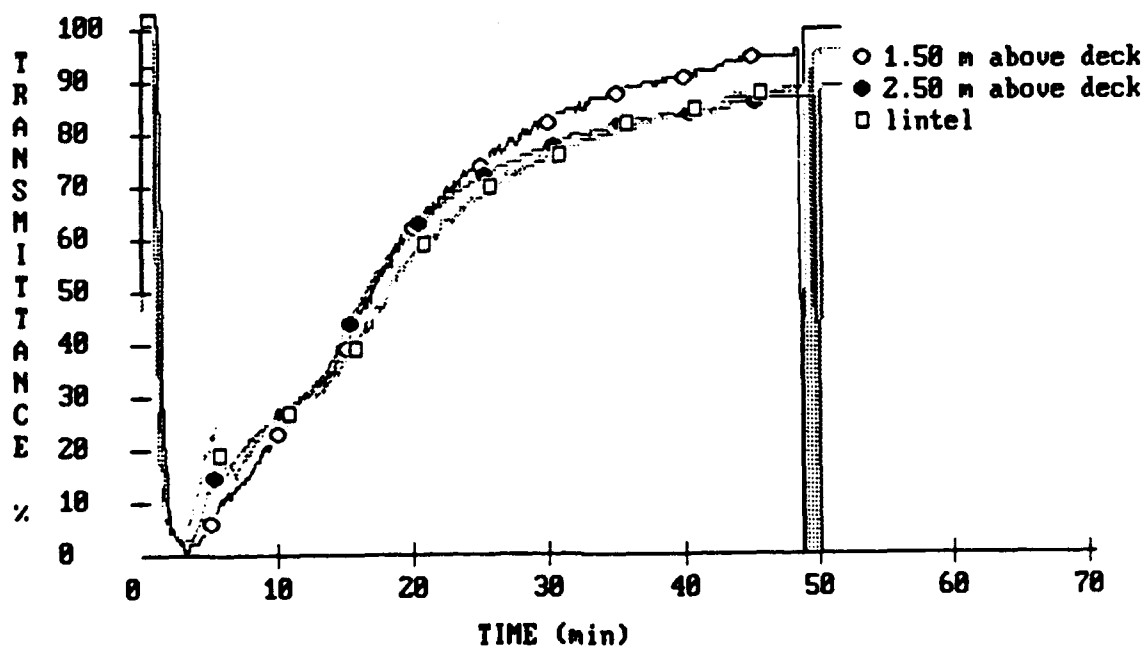


Fig. B-2- Smoke in BERTHING 1 (3-76-2) during Test # 3

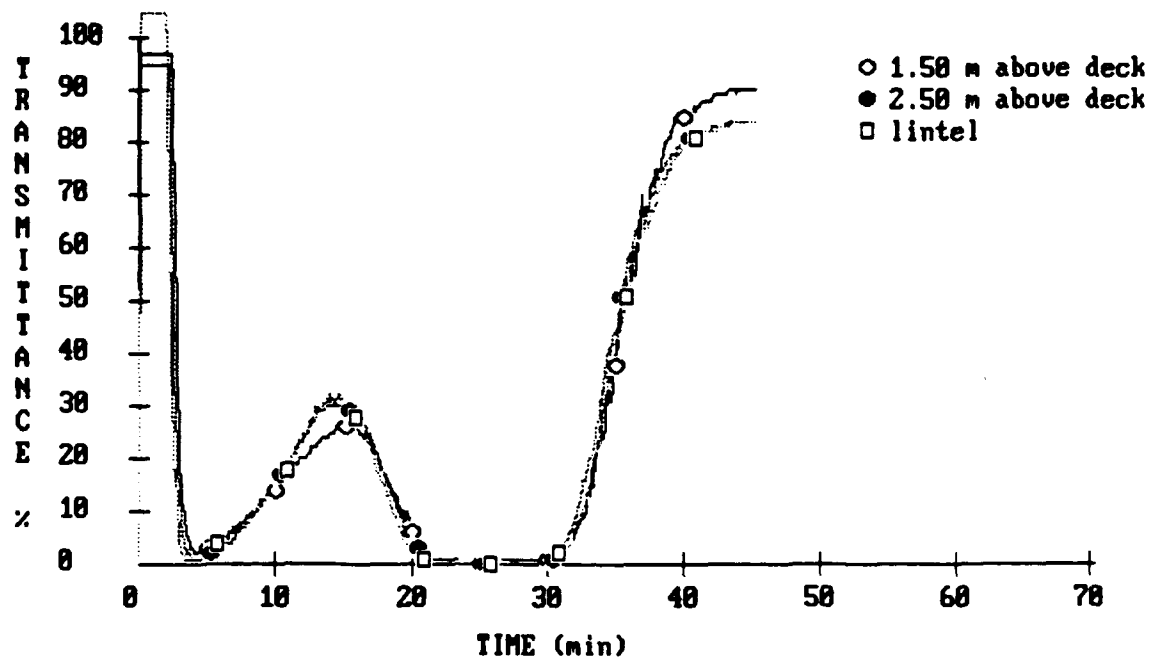


Fig. B-3- Smoke in BERTHING 1 (3-76-2) during Test # 4

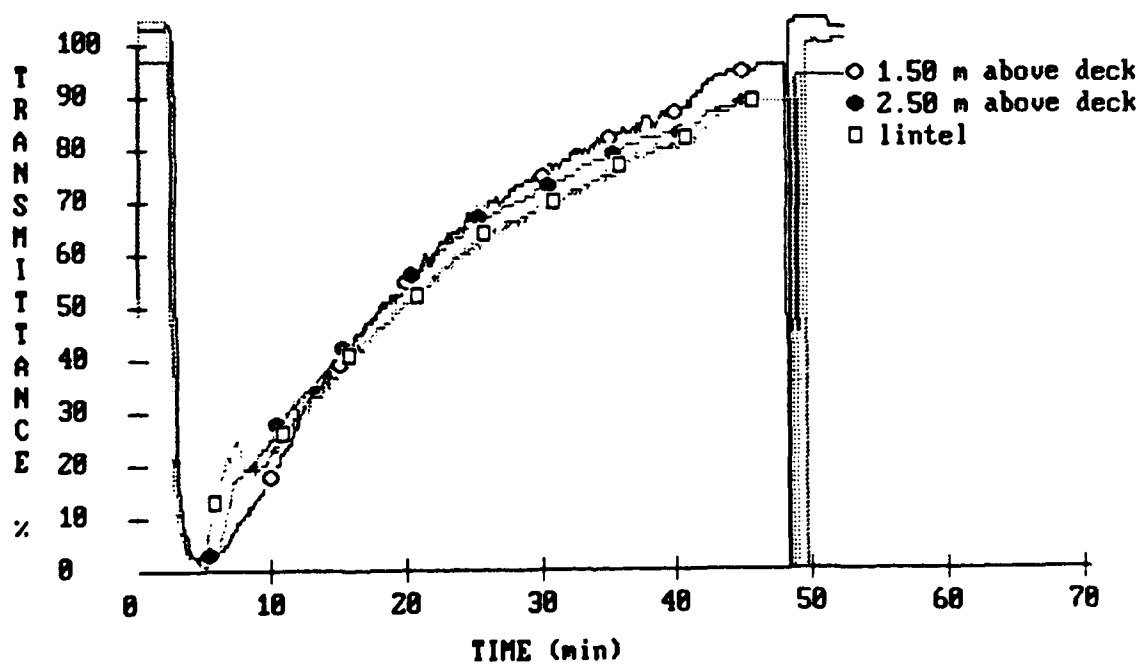


Fig. B-4- Smoke in BERTHING 1 (3-76-2) during Test # 5

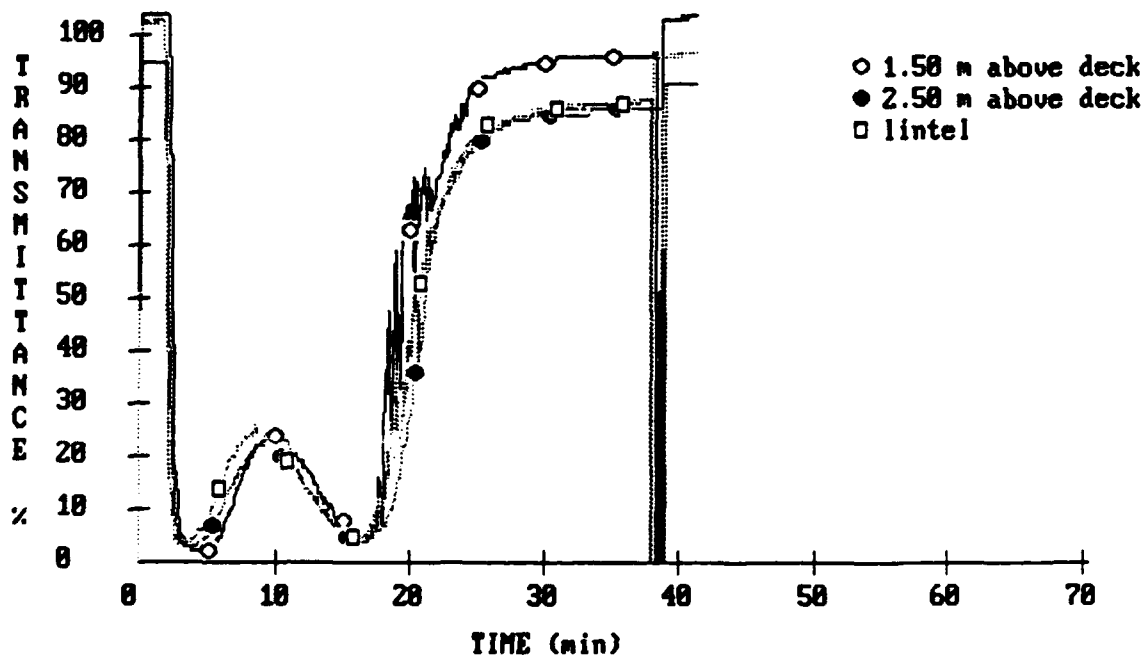


Fig. B-5- Smoke in BERTHING 1 (3-76-2) during Test # 6

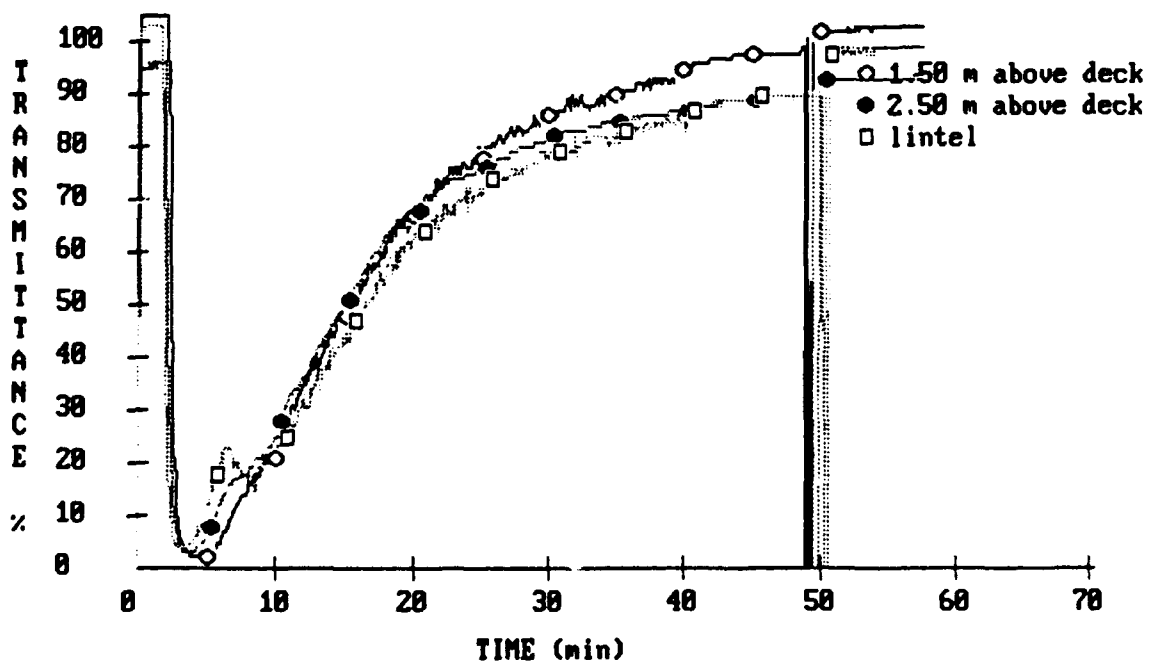


Fig. B-6- Smoke in BERTHING 1 (3-76-2) during Test # 7

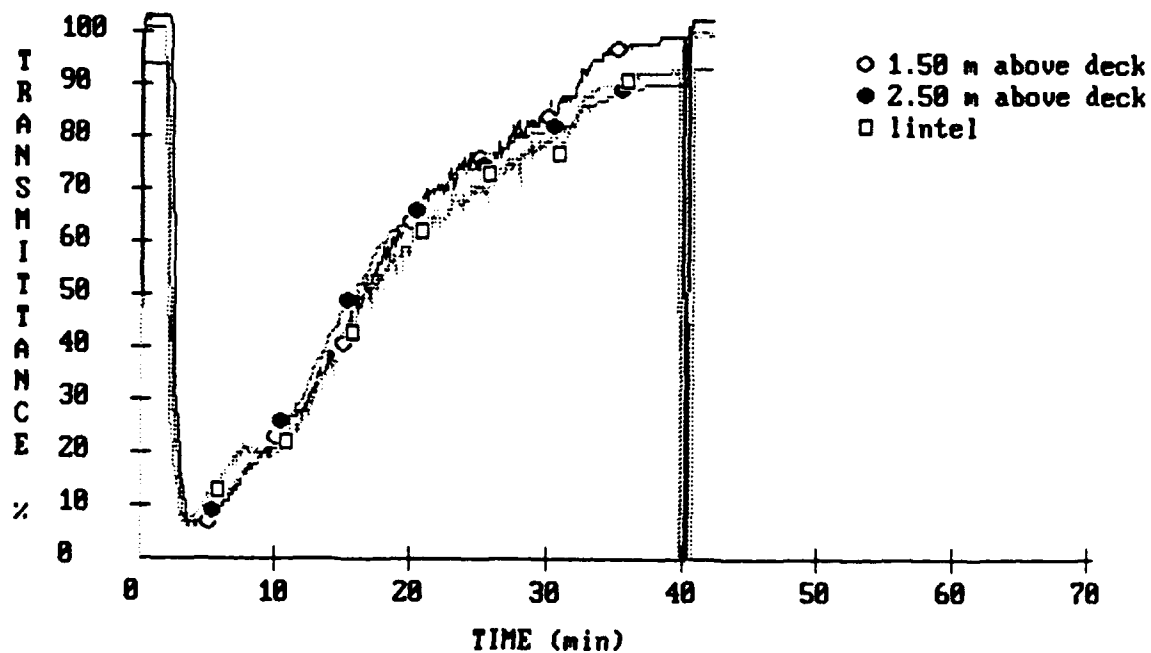


Fig. B-7- Smoke in BERTHING 1 (3-76-2) during Test # 8

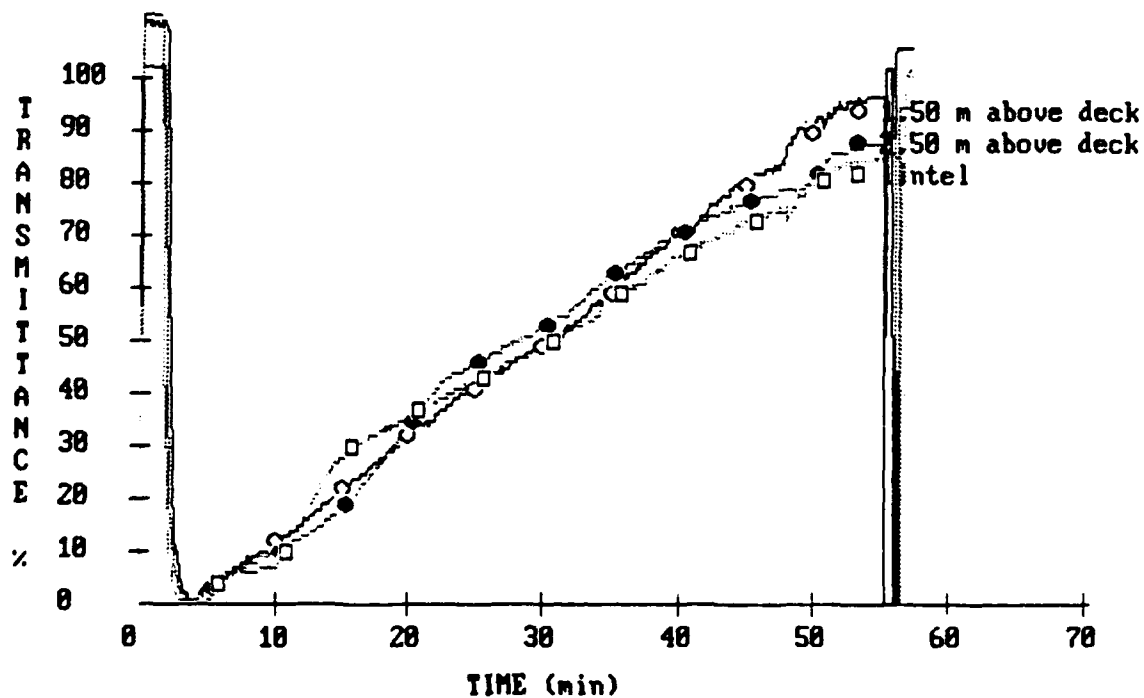


Fig. B-8- Smoke in BERTHING 1 (3-76-2) during Test # 9



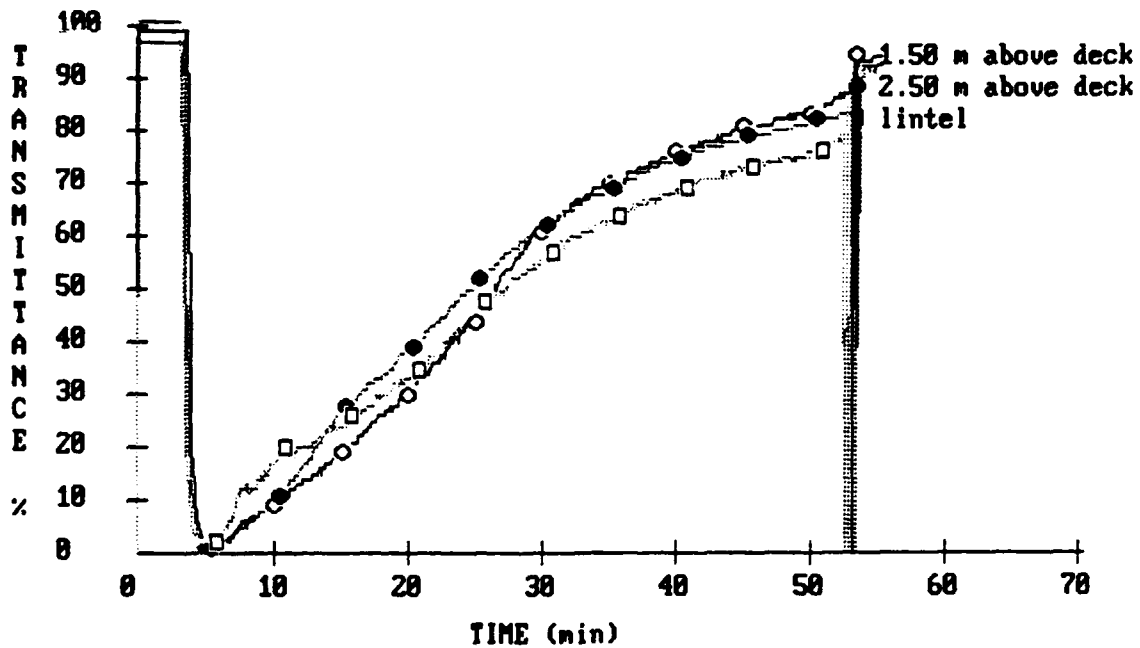


Fig. B-9- Smoke in BERTHING 1 (3-76-2) during Test # 10

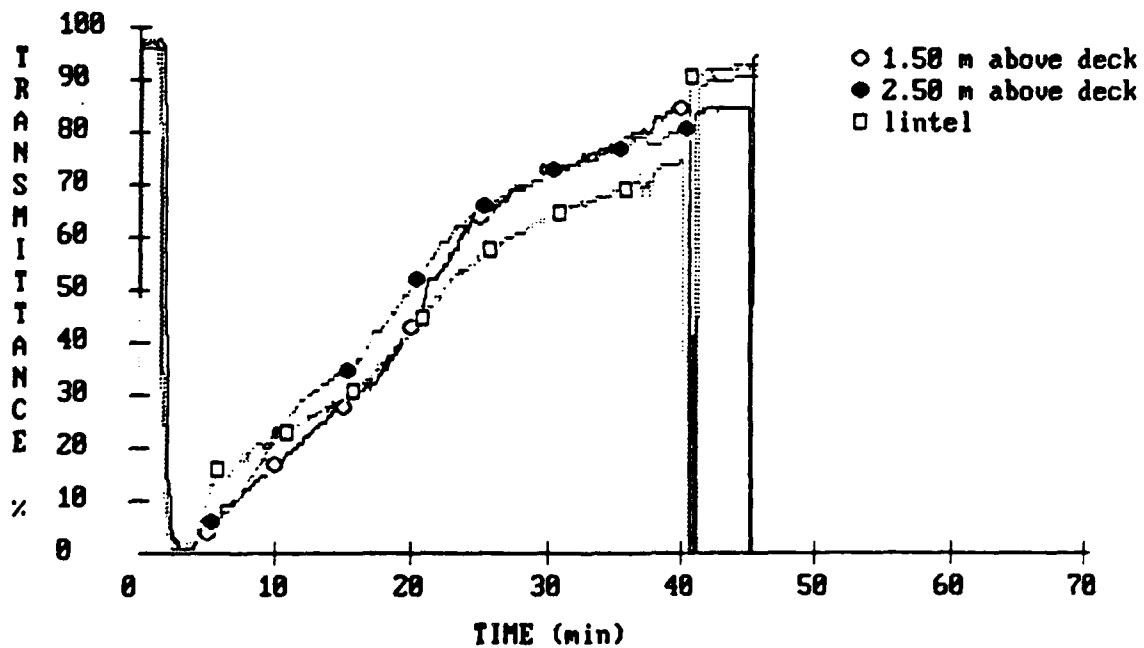


Fig. B-10- Smoke in BERTHING 1 (3-76-2) during Test # 11

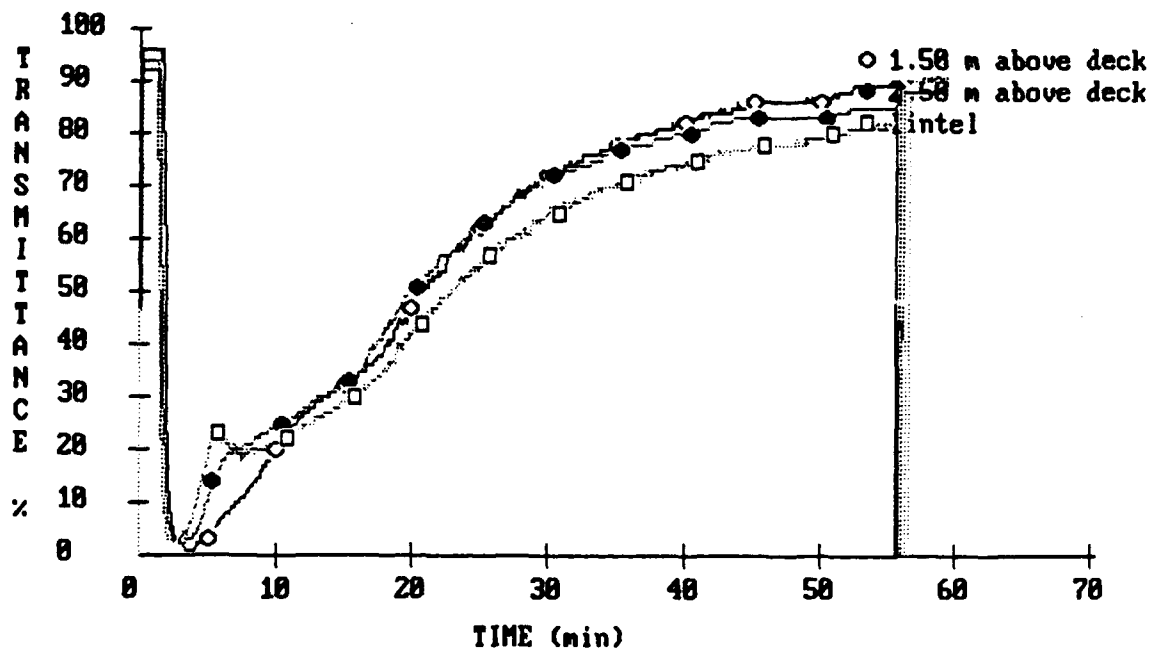


Fig. B-11- Smoke in BERTHING 1 (3-76-2) during Test # 12

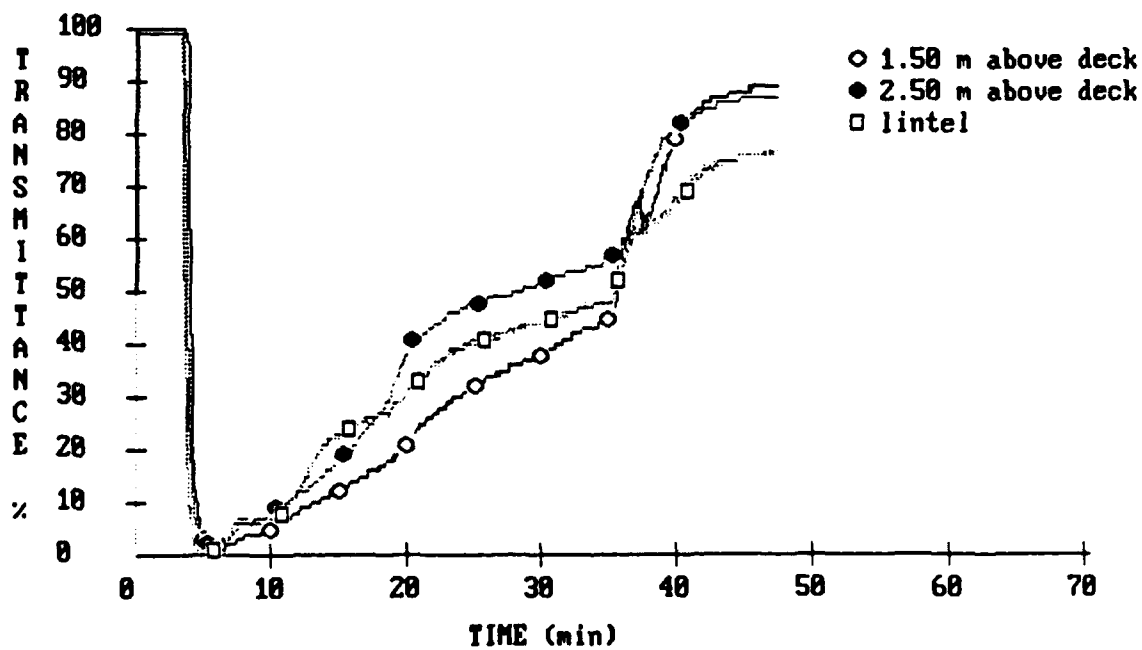


Fig. B-12- Smoke in BERTHING 1 (3-76-2) during Test # 13

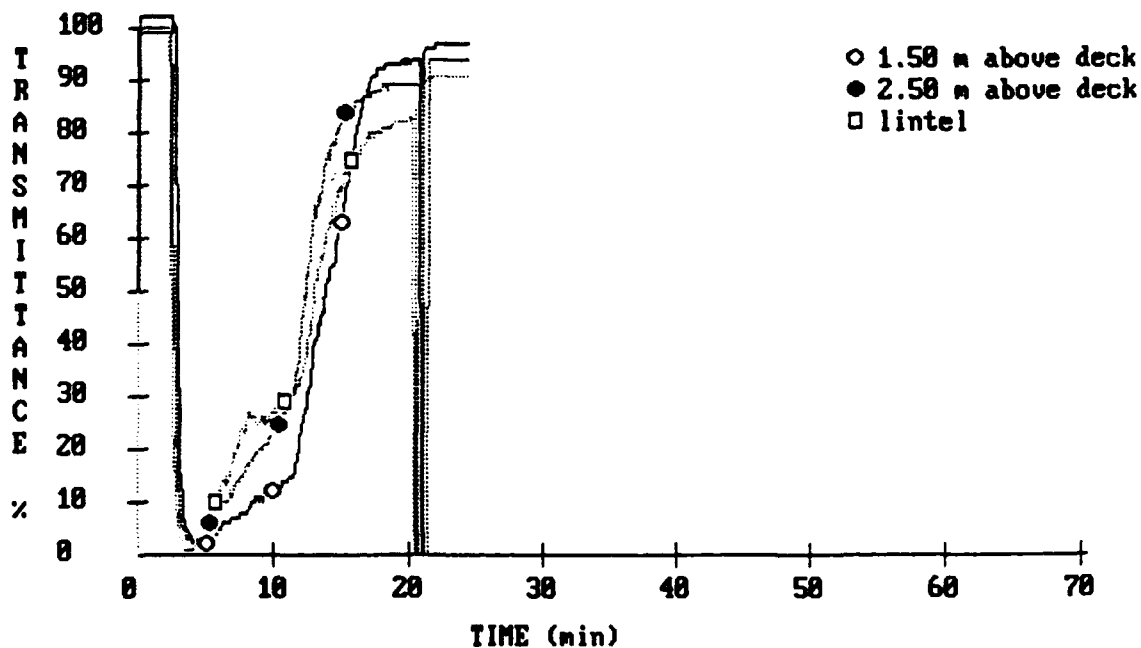


Fig. B-13- Smoke in BERTHING 1 (3-76-2) during Test # 14

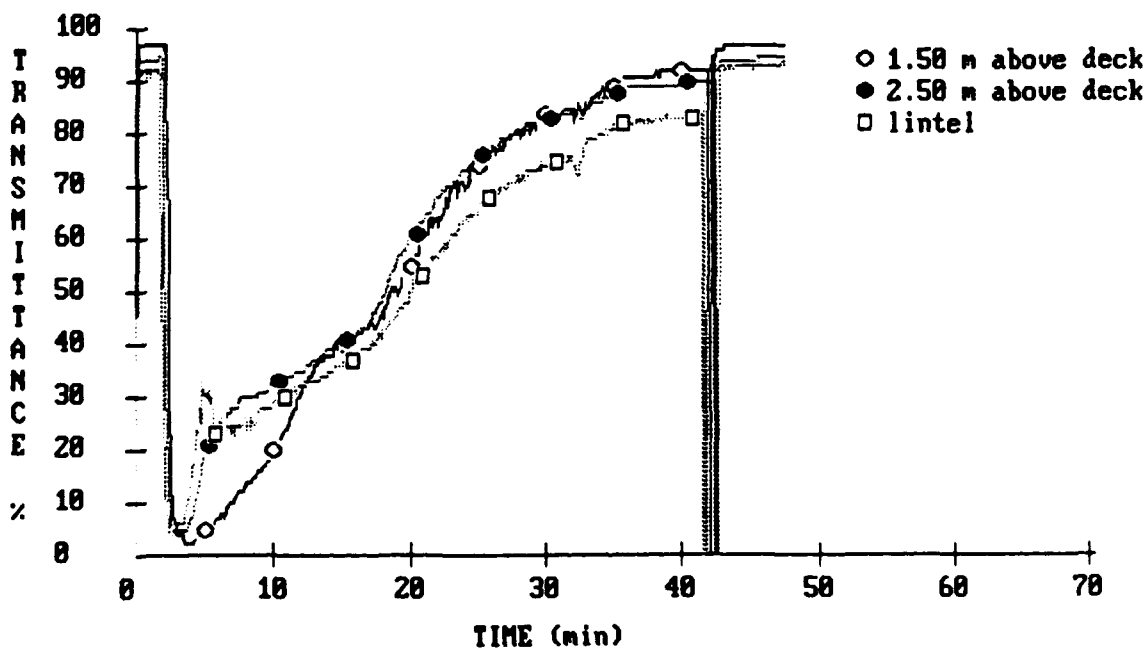


Fig. B-14- Smoke in BERTHING 1 (3-76-2) during Test # 15

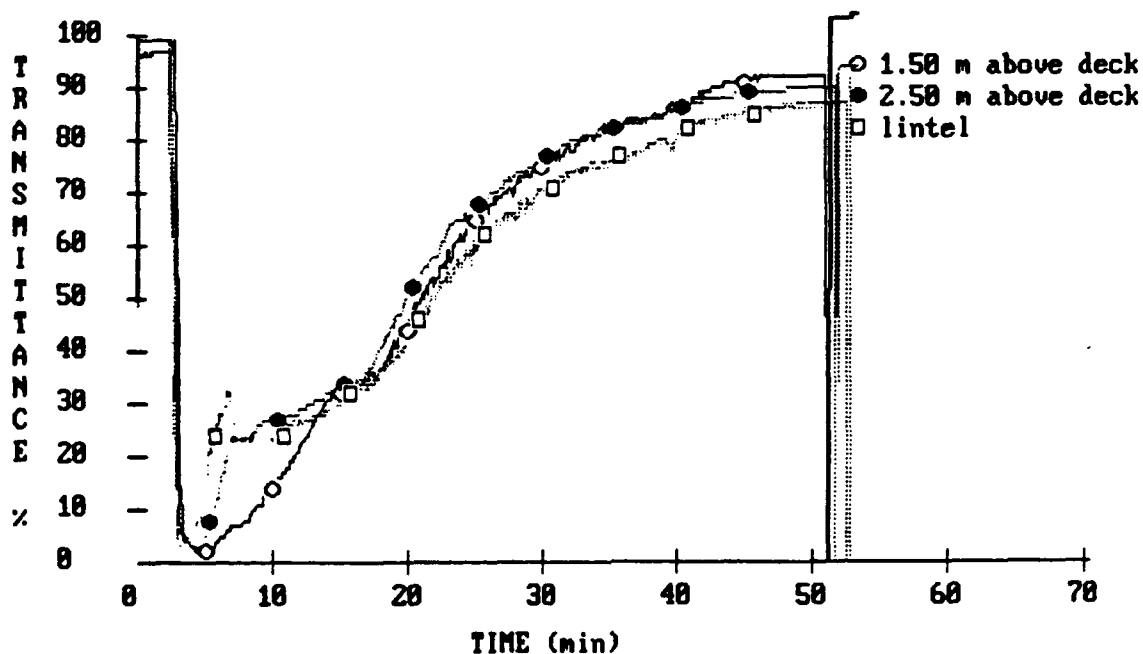


Fig. B-15- Smoke in BERTHING 1 (3-76-2) during Test # 16

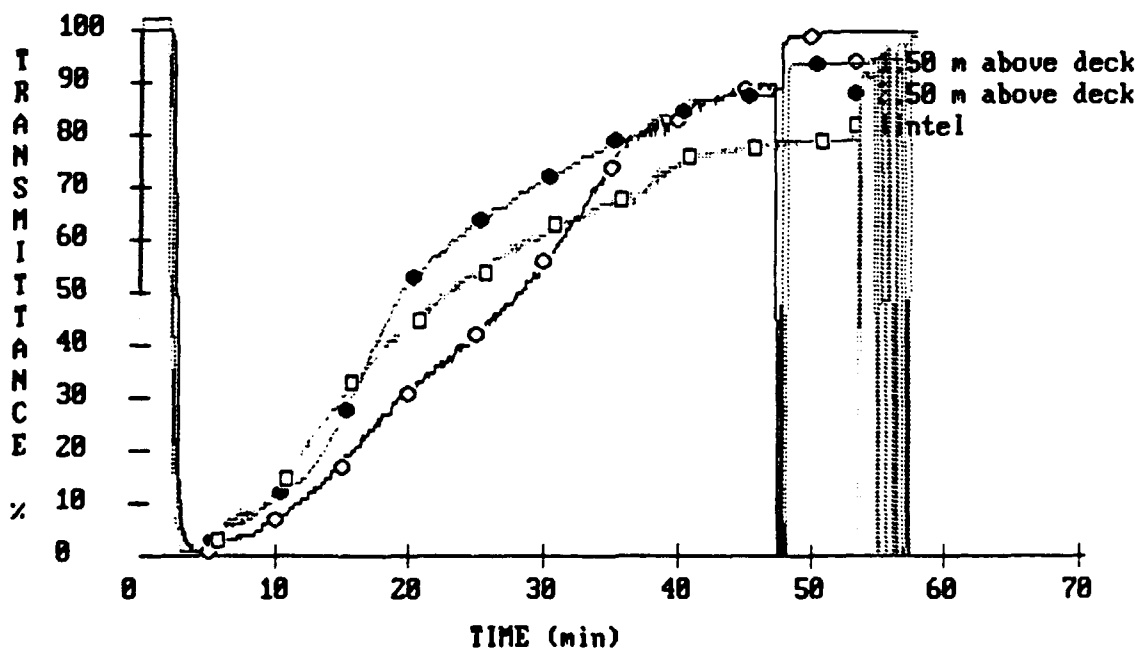


Fig. B-16- Smoke in BERTHING 1 (3-76-2) during Test # 17

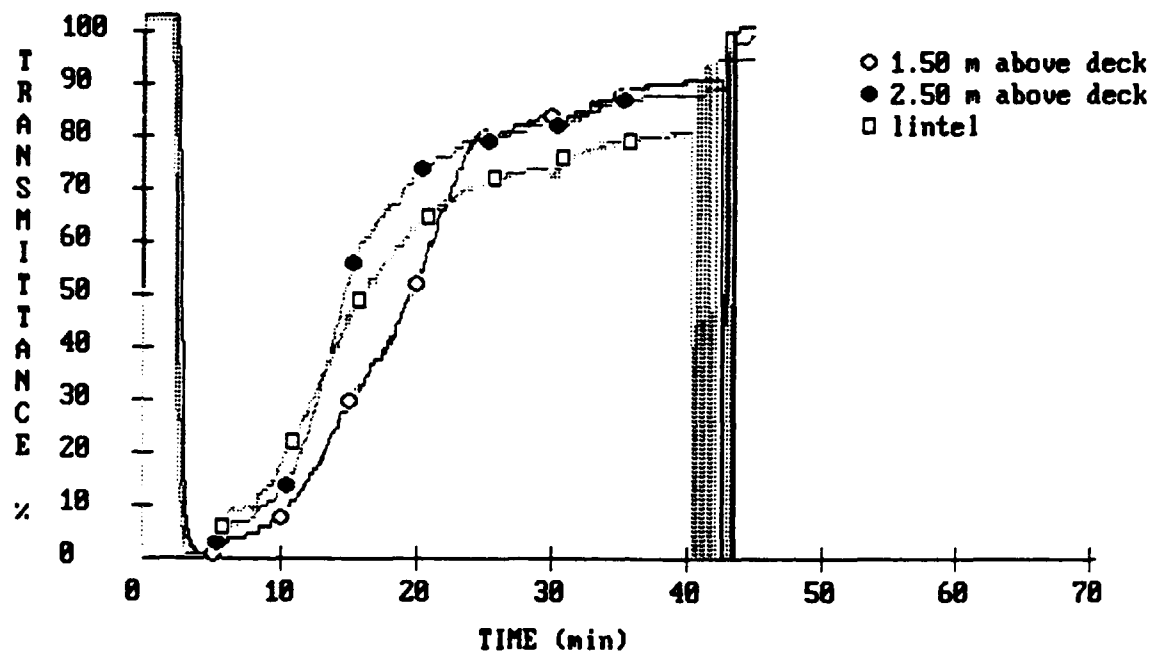


Fig. B-17- Smoke in BERTHING 1 (3-76-2) during Test # 18

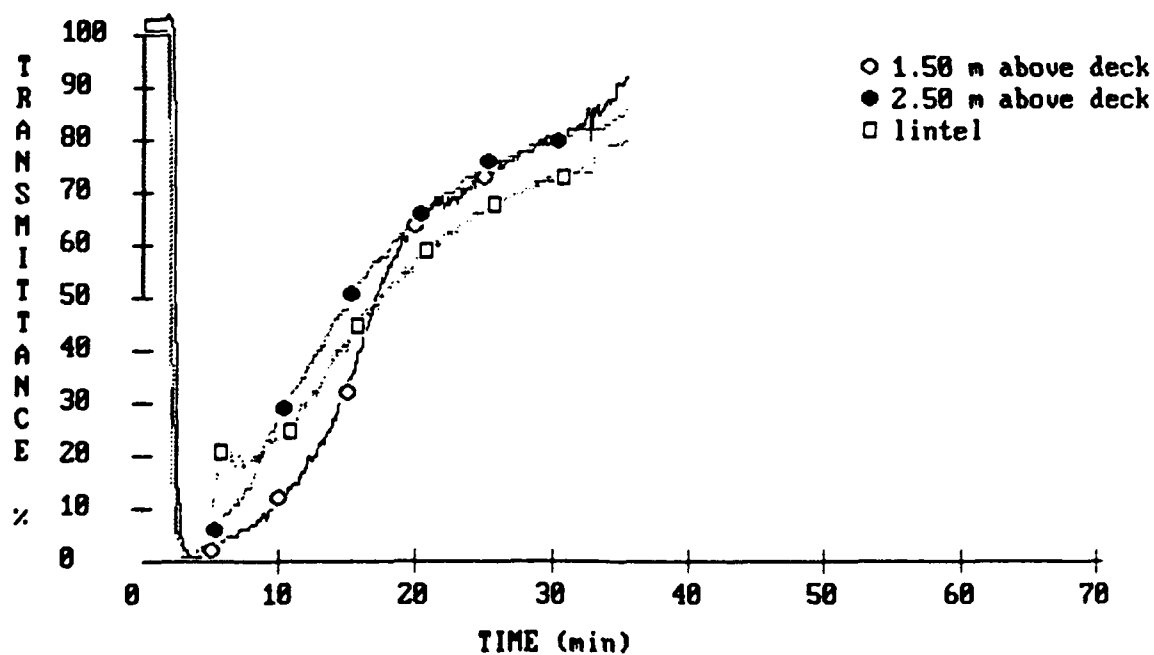


Fig. B-18- Smoke in BERTHING 1 (3-76-2) during Test # 19

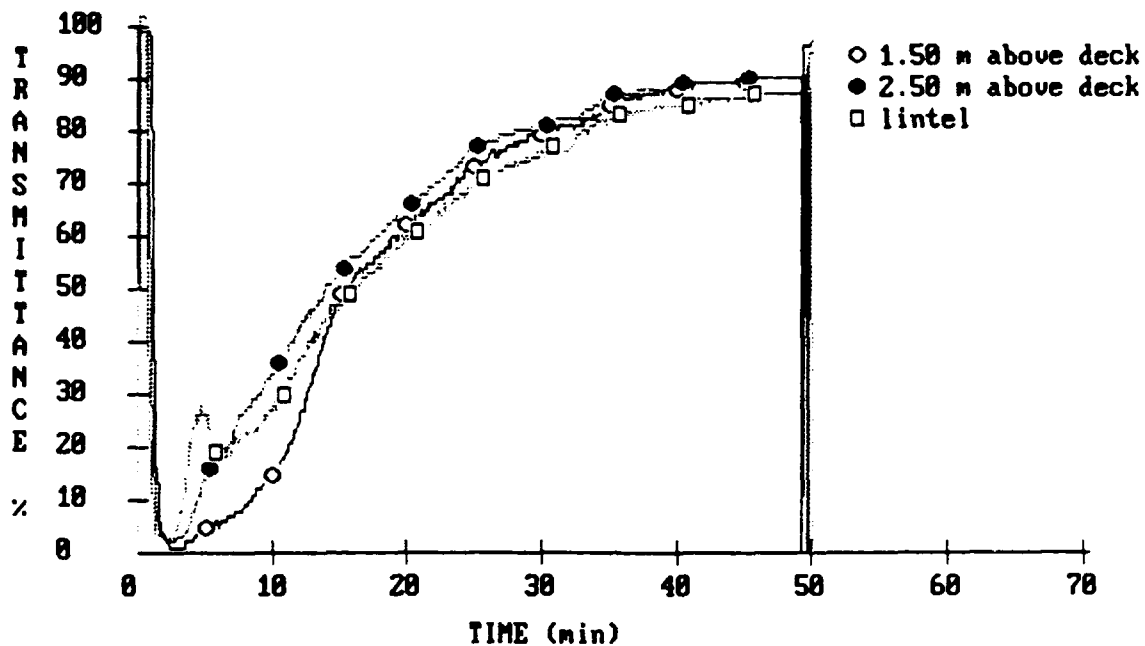


Fig. B-19- Smoke in BERTHING 1 (3-76-2) during Test # 20

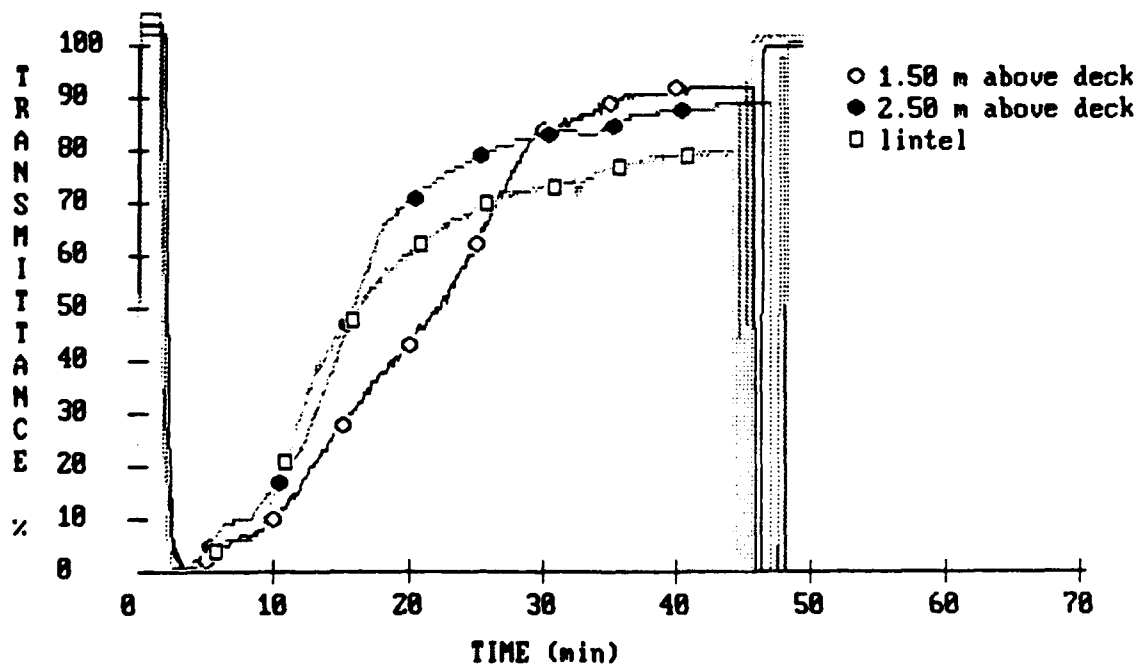


Fig. B-20- Smoke in BERTHING 1 (3-76-2) during Test # 21

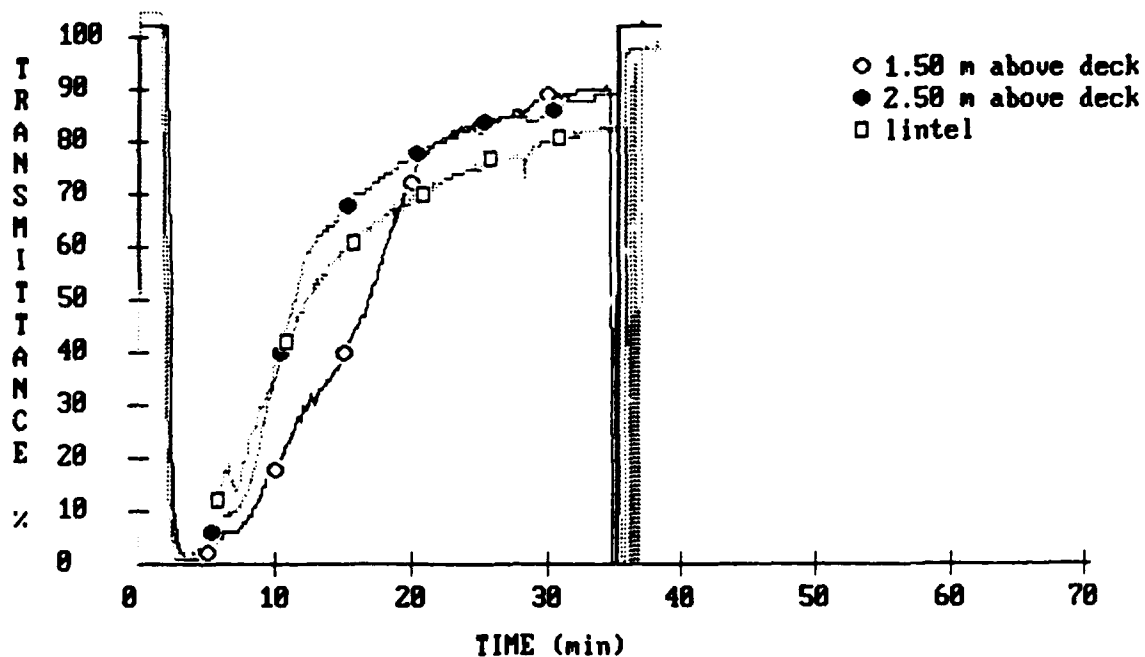


Fig. B-21- Smoke in BERTHING 1 (3-76-2) during Test # 22

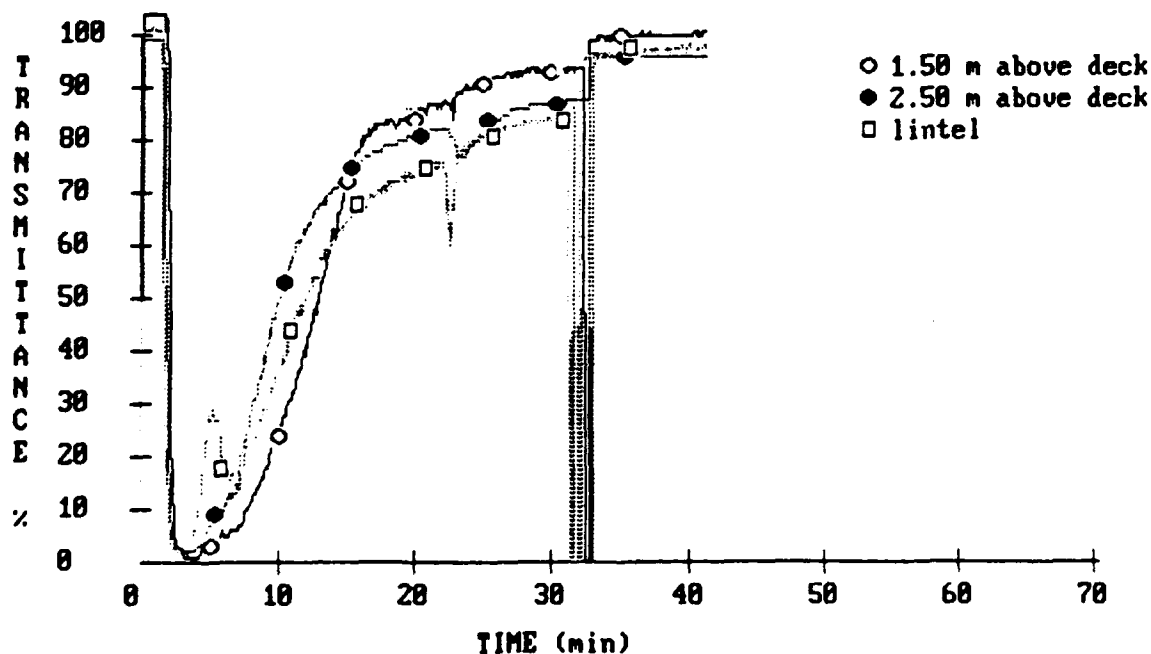


Fig. B-22- Smoke in BERTHING 1 (3-76-2) during Test # 23

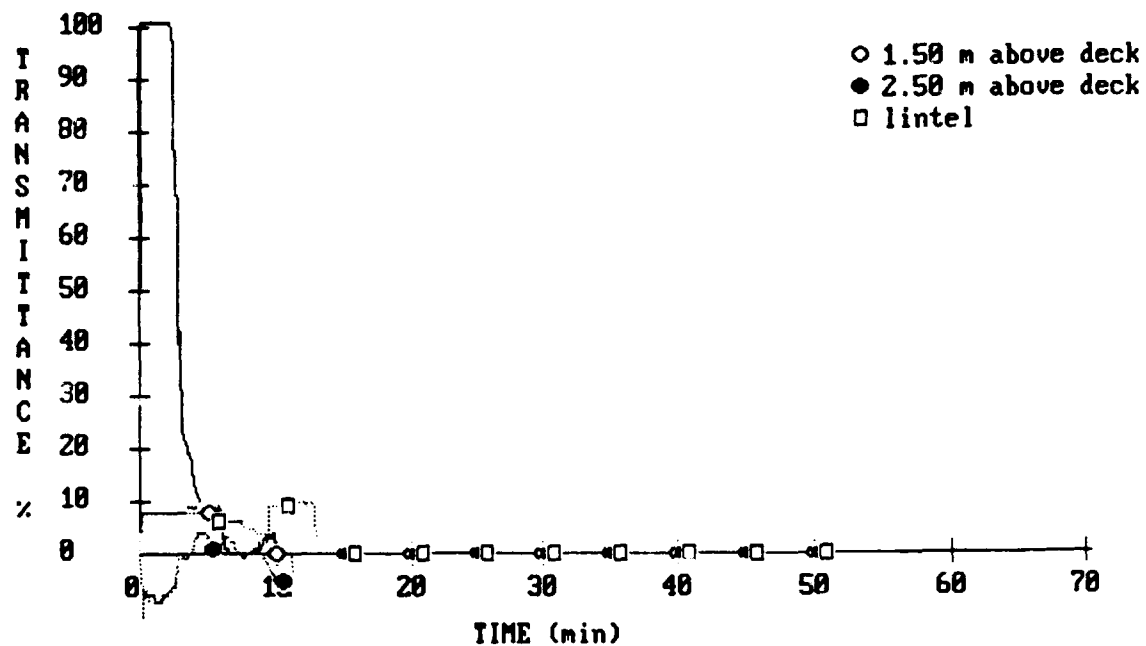


Fig. B-23- Smoke in BERTHING 1 (3-76-2) during Test # 24

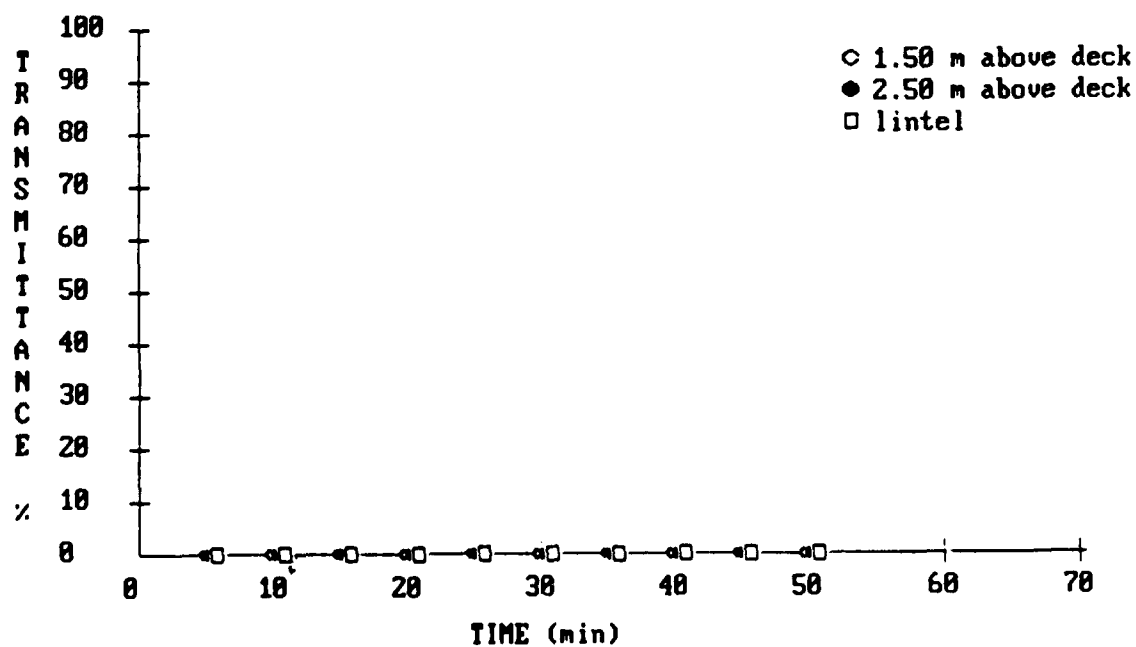


Fig. B-24- Smoke in BERTHING 1 (3-76-2) during Test # 25



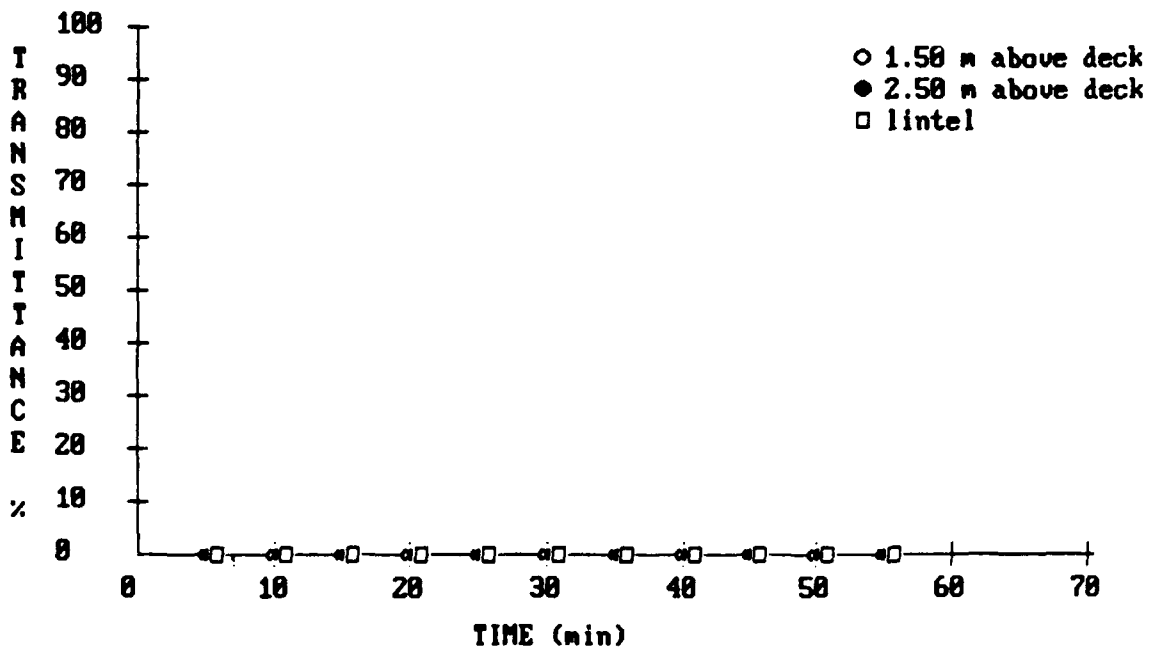


Fig. B-25- Smoke in BERTHING 1 (3-76-2) during Test # 26

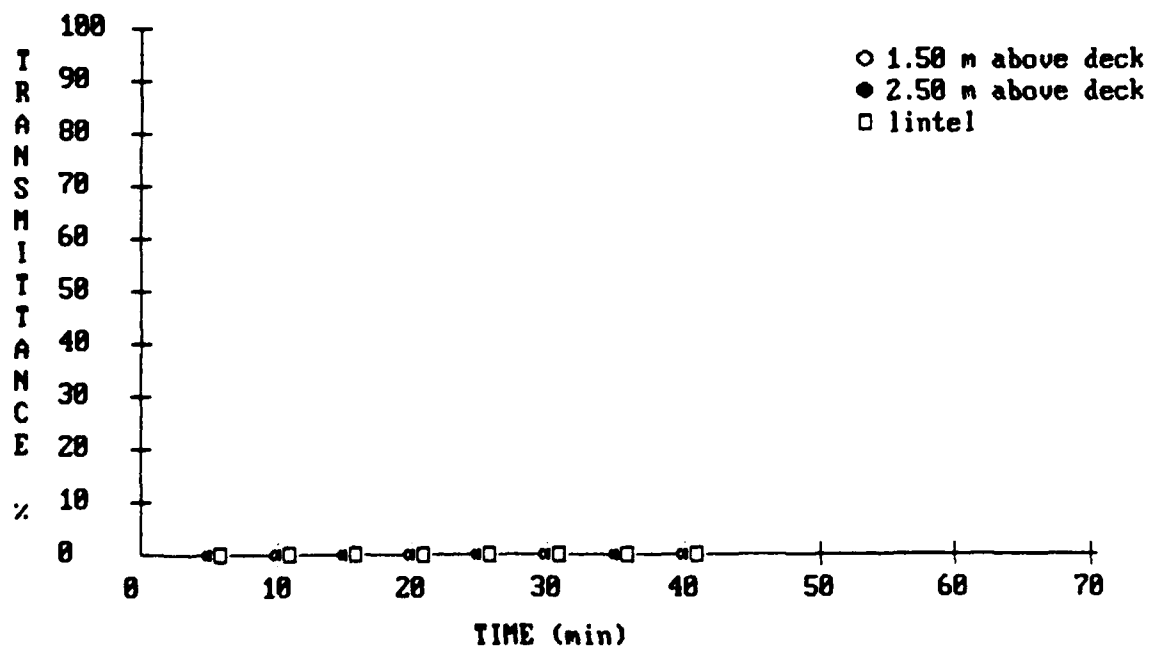


Fig. B-26- Smoke in BERTHING 1 (3-76-2) during Test # 27

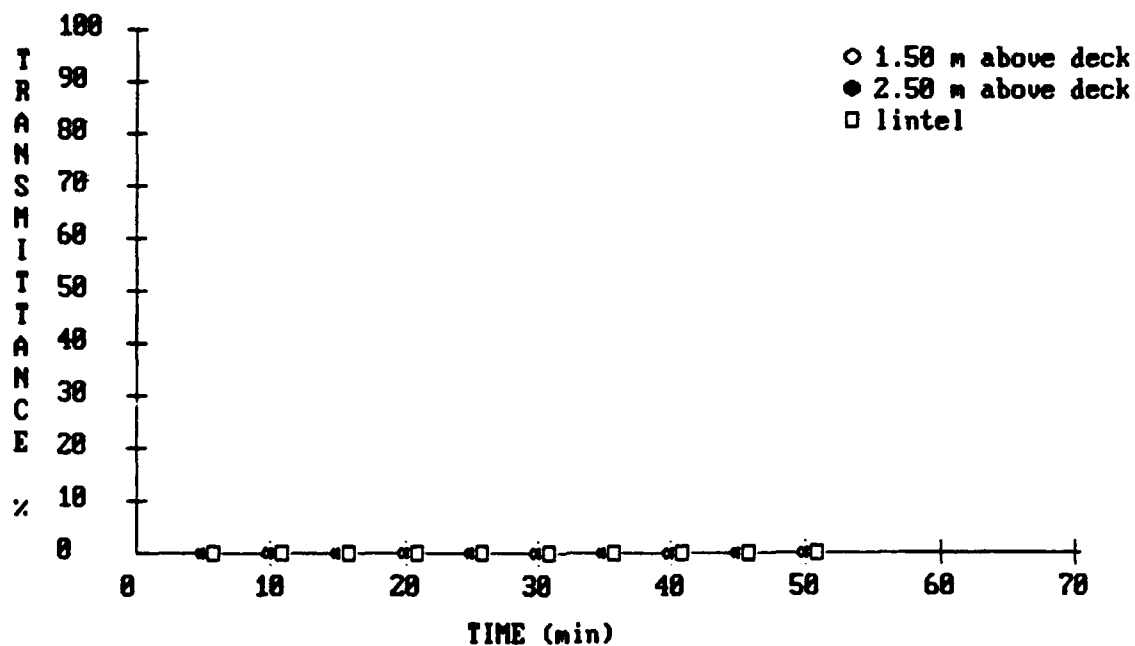


Fig. B-27- Smoke in BERTHING 1 (3-76-2) during Test # 28

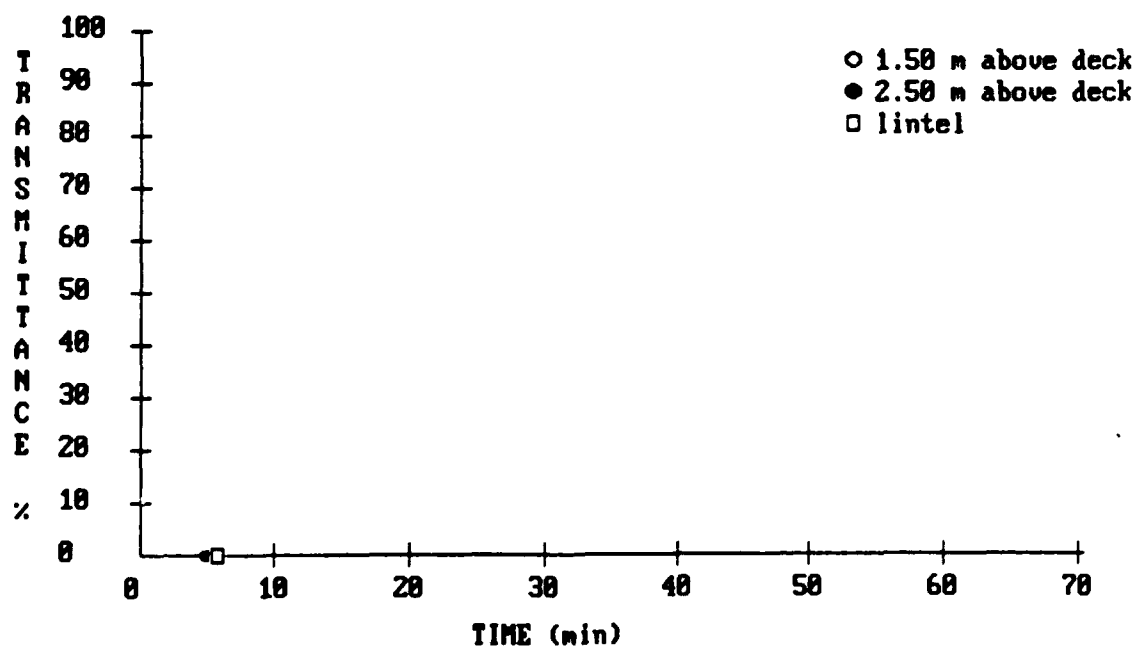


Fig. B-28- Smoke in BERTHING 1 (3-76-2) during Test # 29

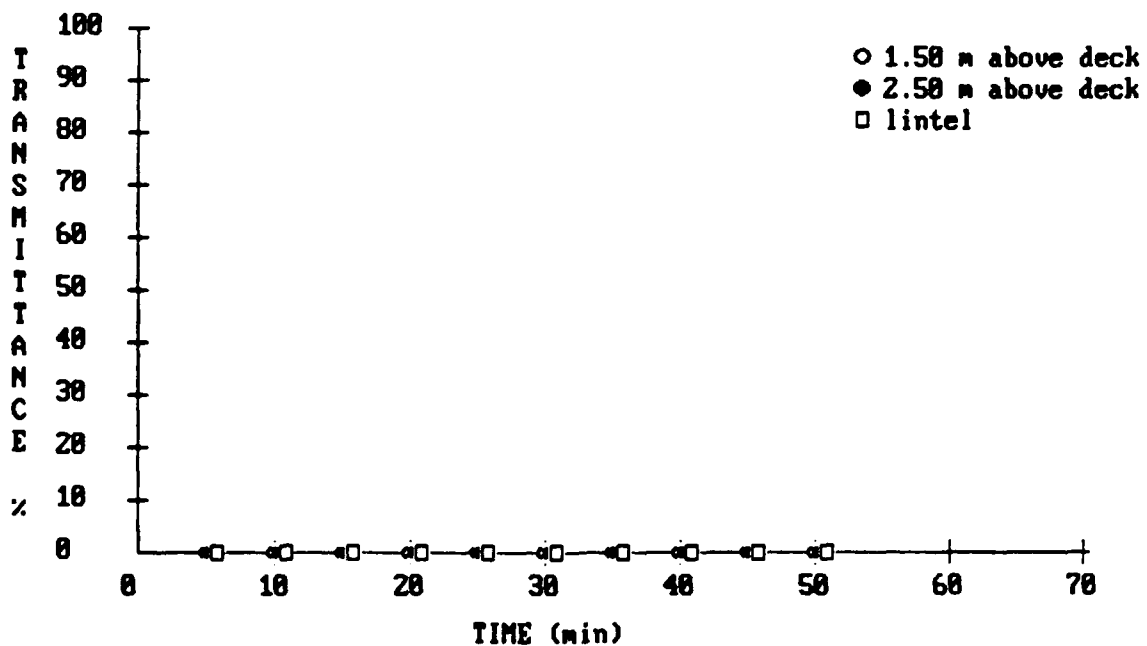


Fig. B-29- Smoke in BERTHING 1 (3-76-2) during Test # 30

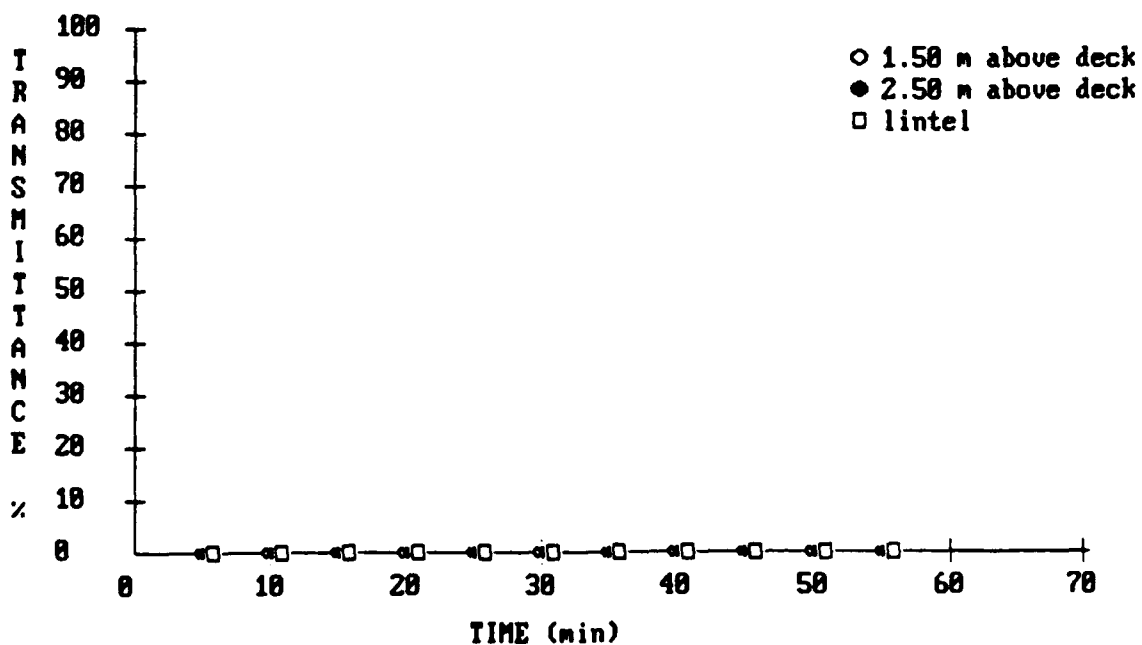


Fig. B-30- Smoke in BERTHING 1 (3-76-2) during Test # 31

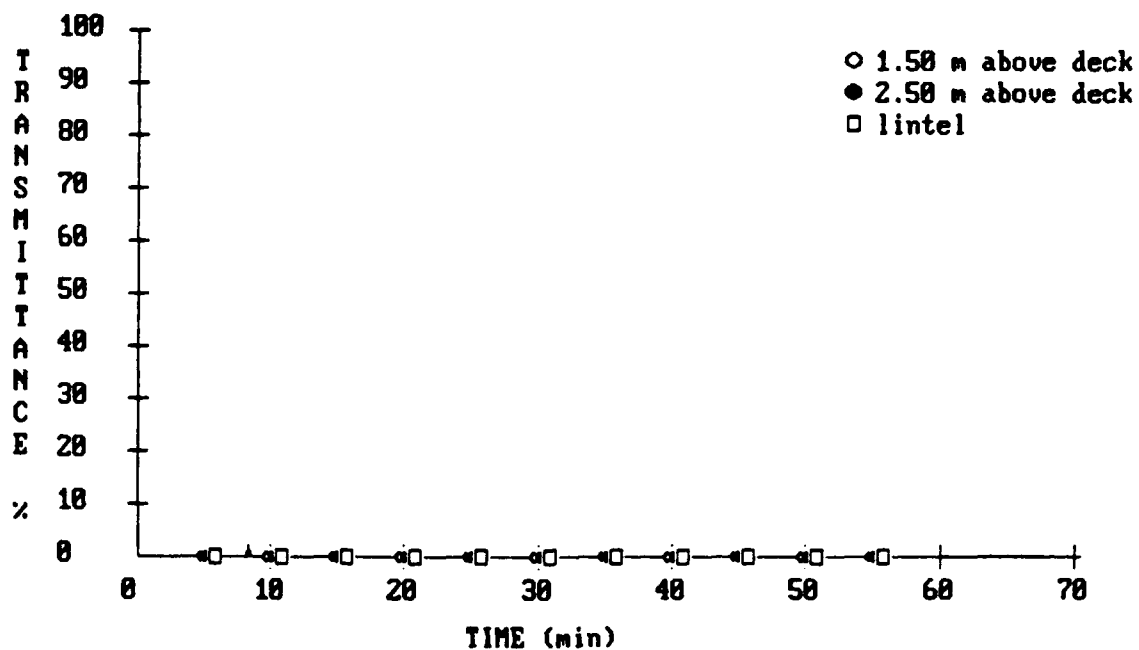


Fig. B-31- Smoke in BERTHING 1 (3-76-2) during Test # 32

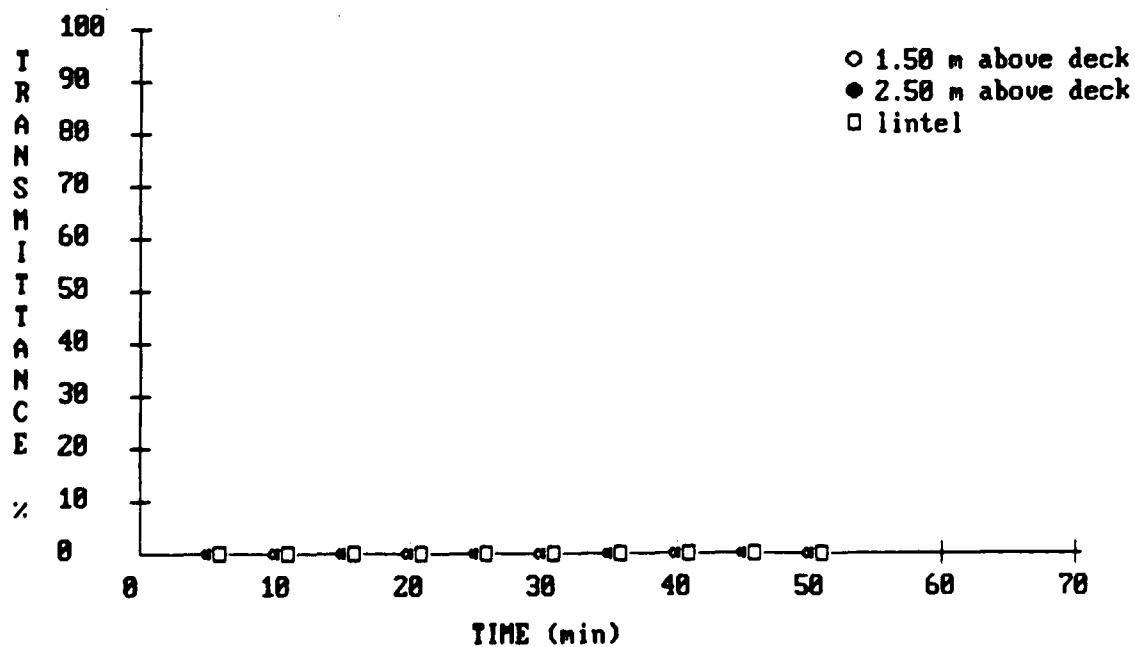


Fig. B-32- Smoke in BERTHING 1 (3-76-2) during Test # 33

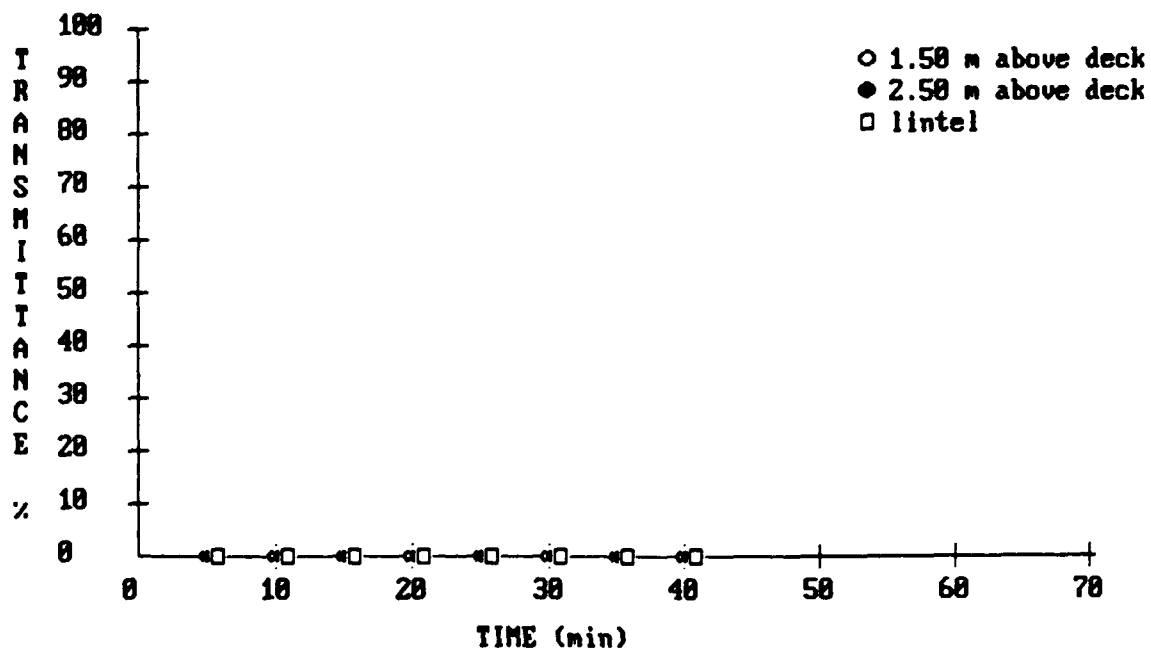


Fig. B-33- Smoke in BERTHING 1 (3-76-2) during Test # 34

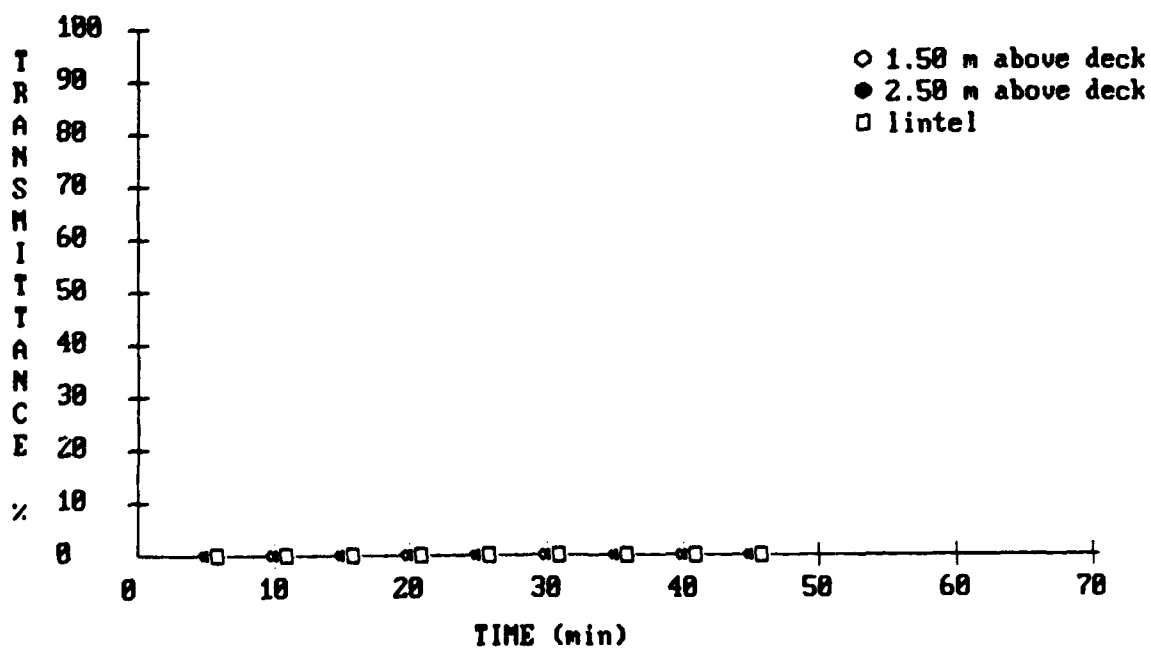


Fig. B-34- Smoke in BERTHING 1 (3-76-2) during Test # 35

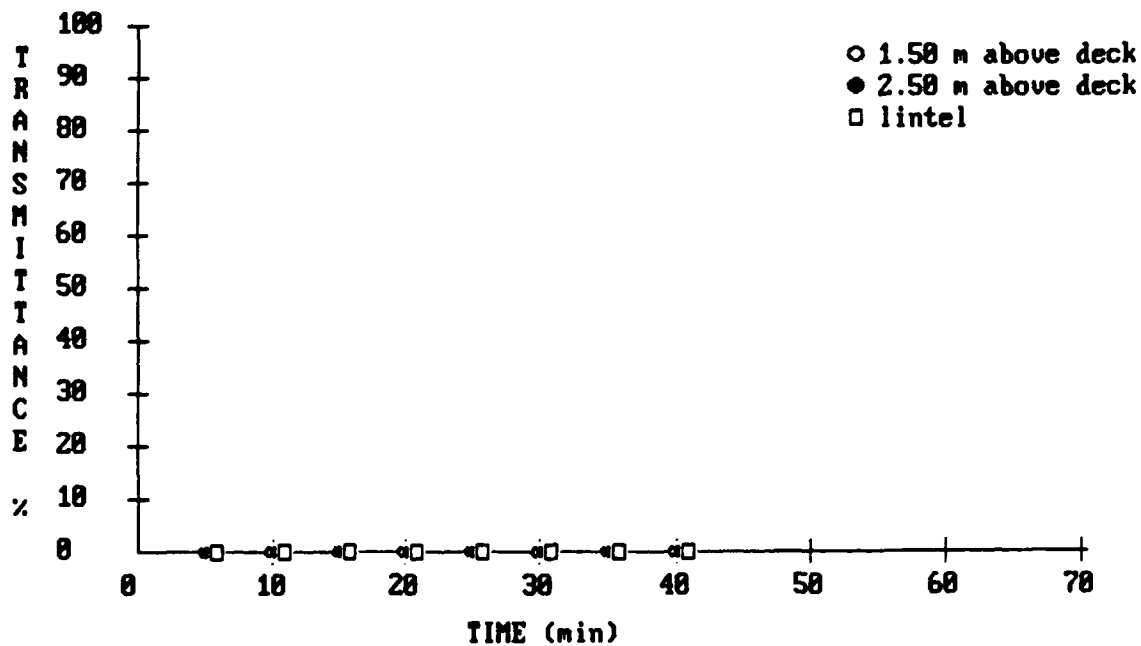


Fig. B-35- Smoke in BERTHING 1 (3-76-2) during Test # 36

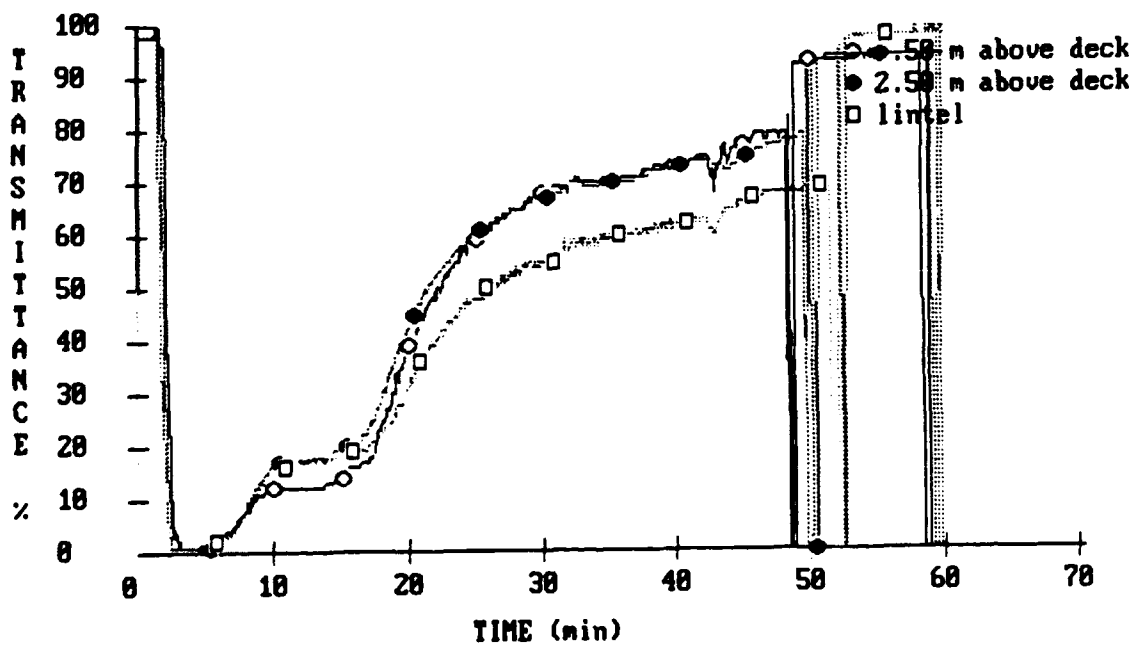


Fig. B-36- Smoke in BERTHING 1 (3-76-2) during Test # 37

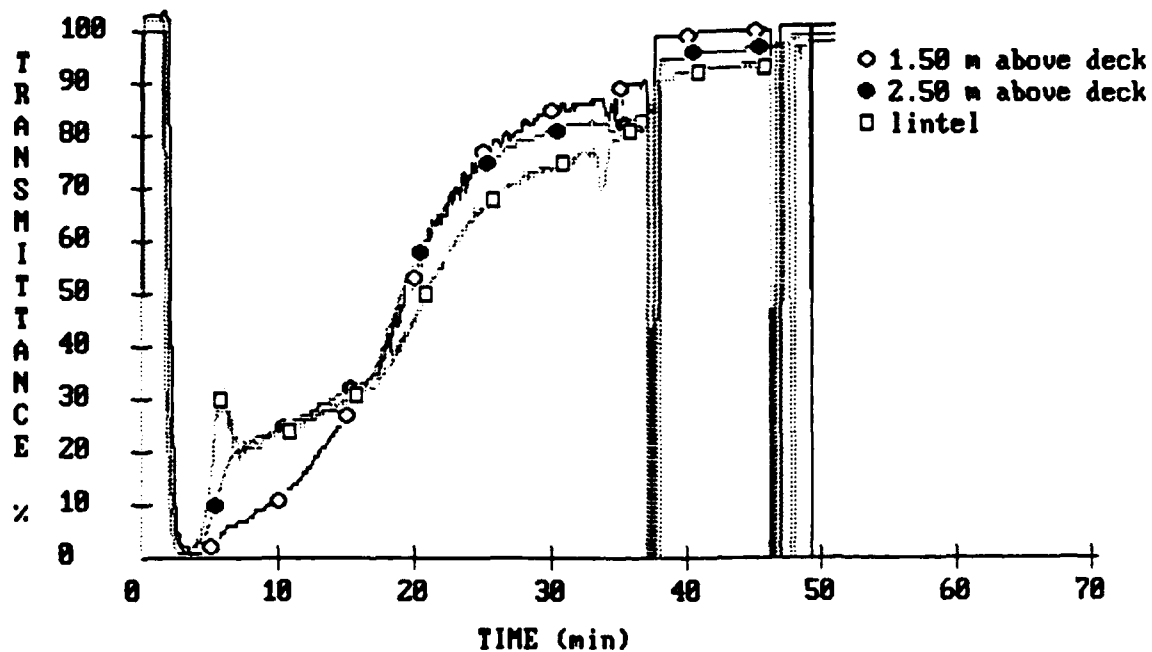


Fig. B-37- Smoke in BERTHING 1 (3-76-2) during Test # 38

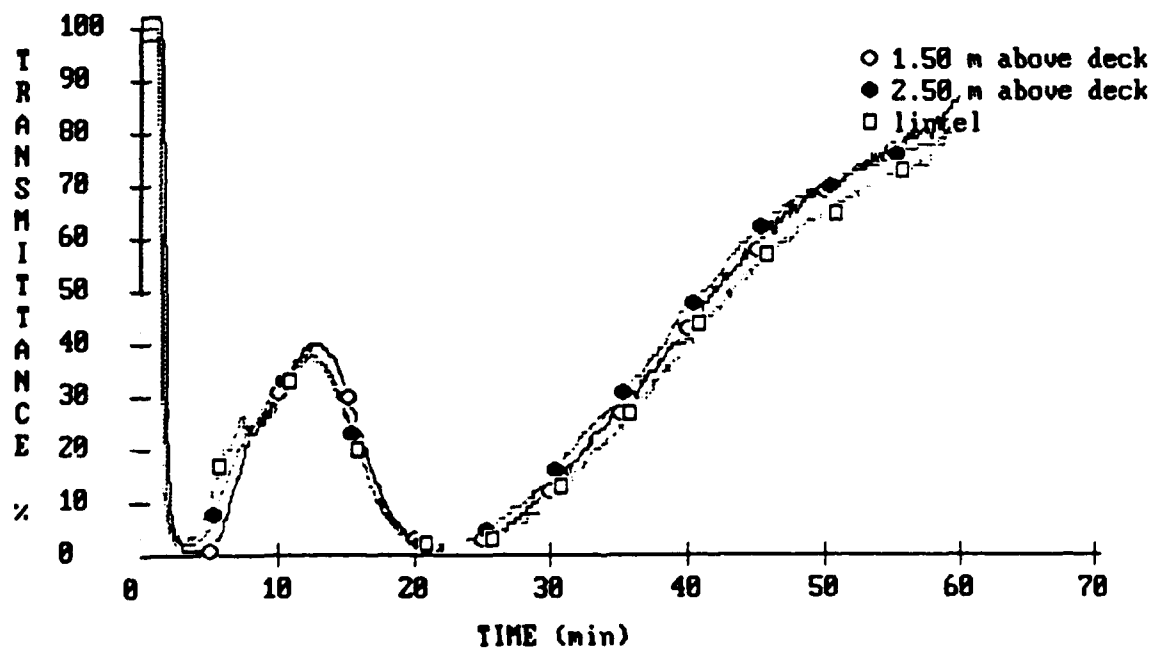


Fig. B-38- Smoke in BERTHING 1 (3-76-2) during Test # 39

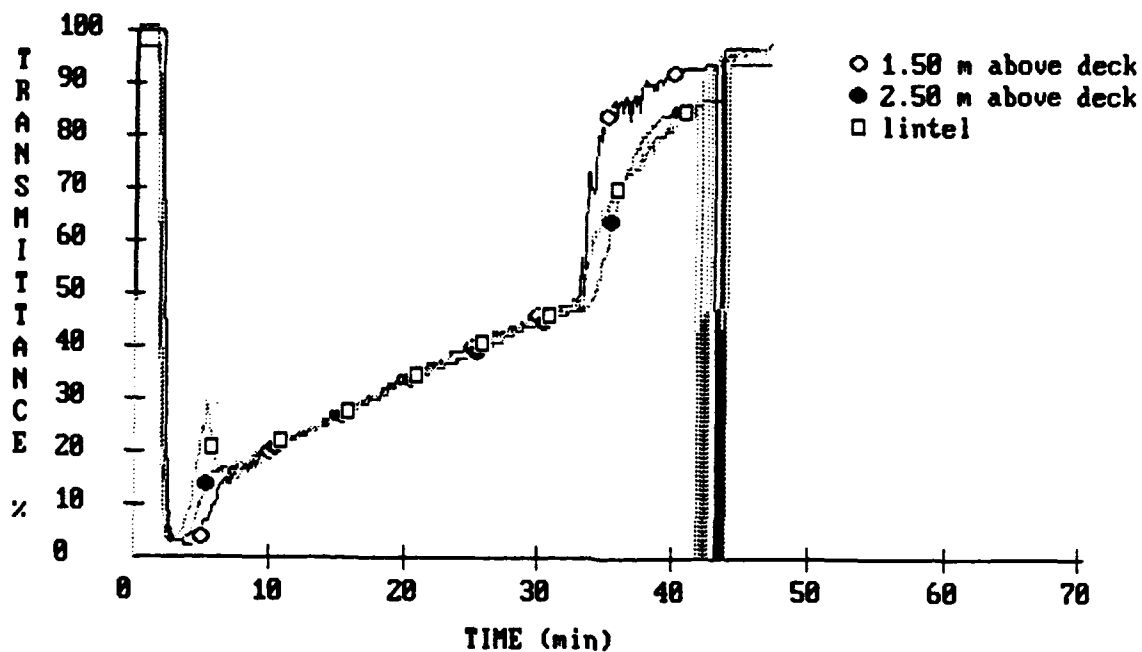


Fig. B-39- Smoke in BERTHING 1 (3-76-2) during Test # 40

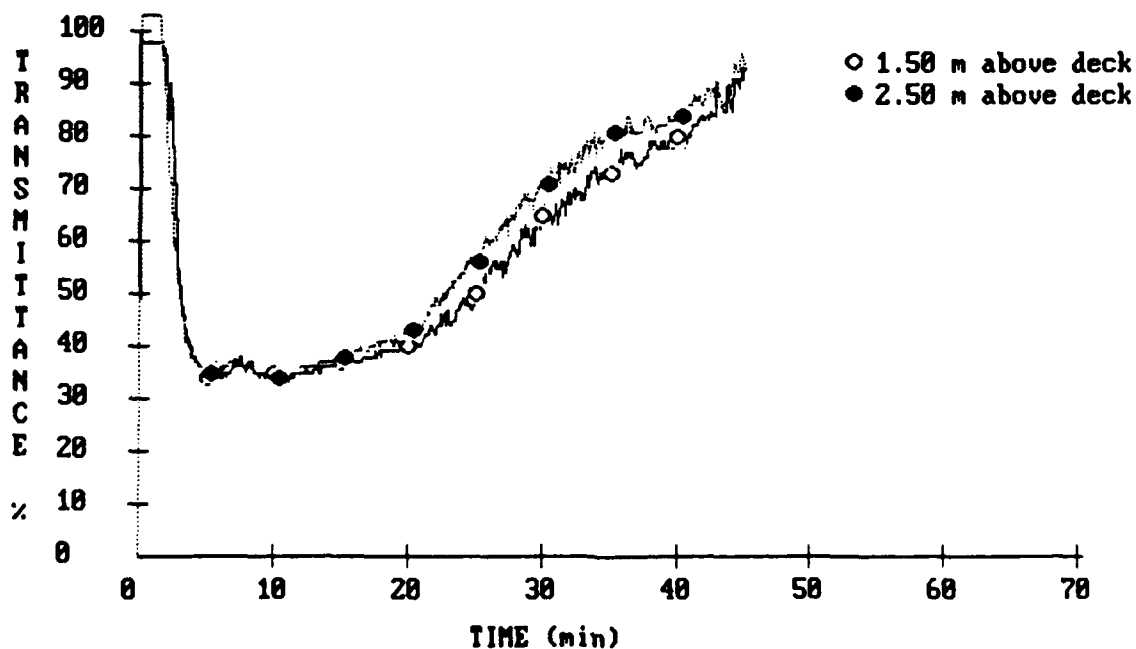


Fig. B-40- Smoke in RICER 1 (2-76-2) during Test # 2



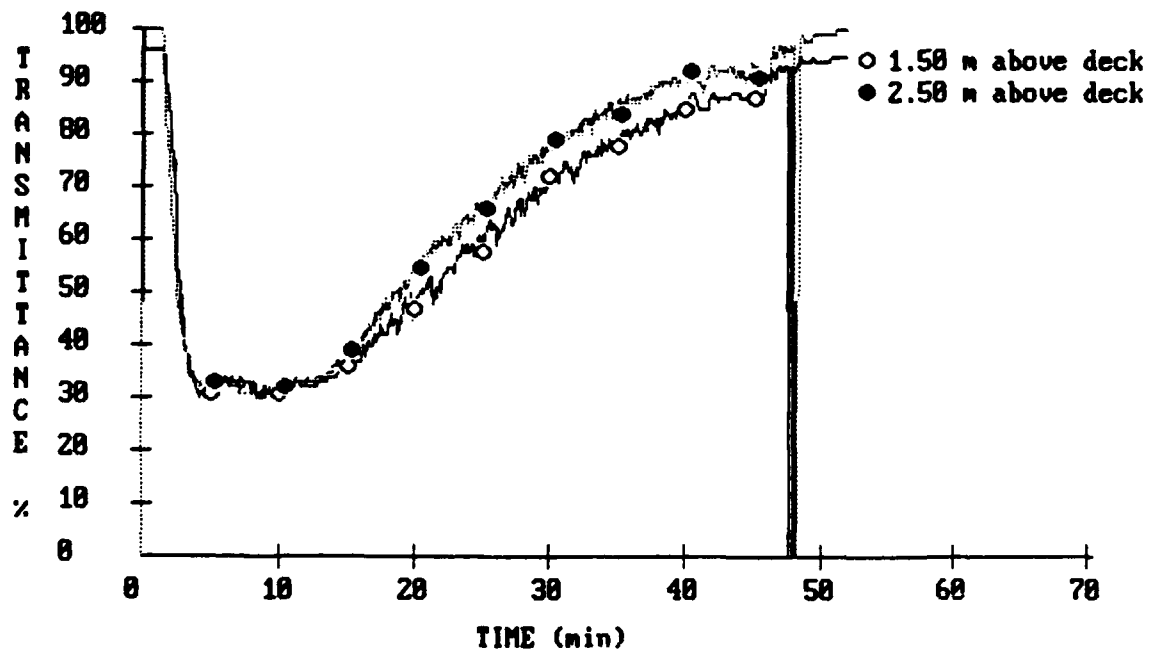


Fig. B-41- Smoke in RICER 1 (2-76-2) during Test # 3

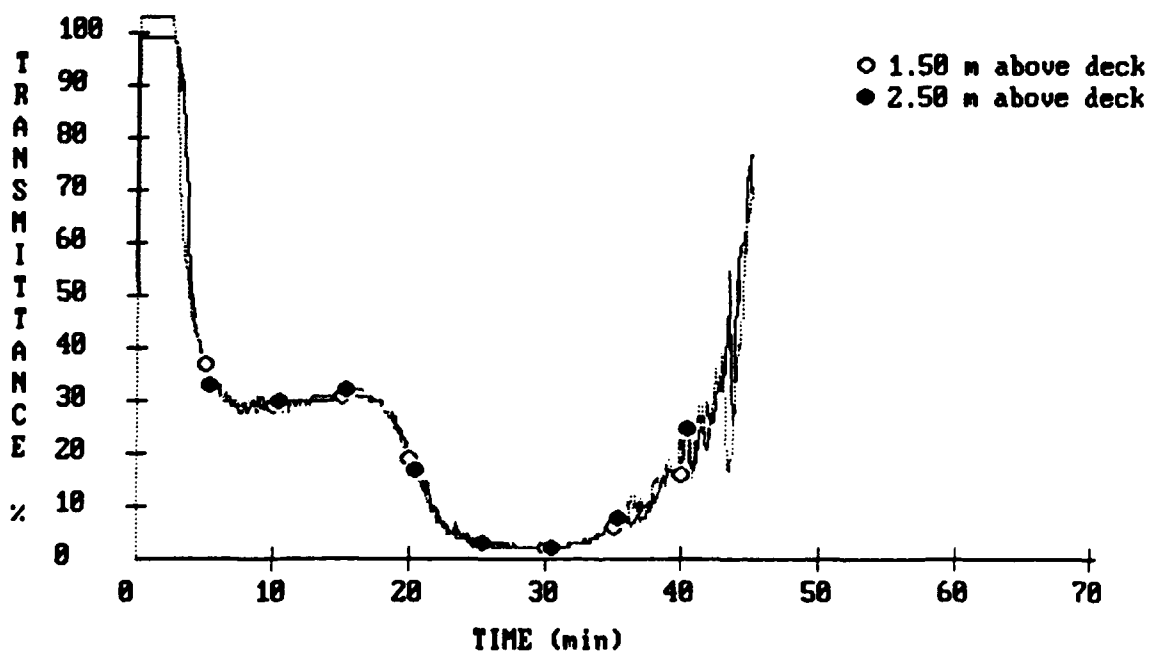


Fig. B-42- Smoke in RICER 1 (2-76-2) during Test # 4

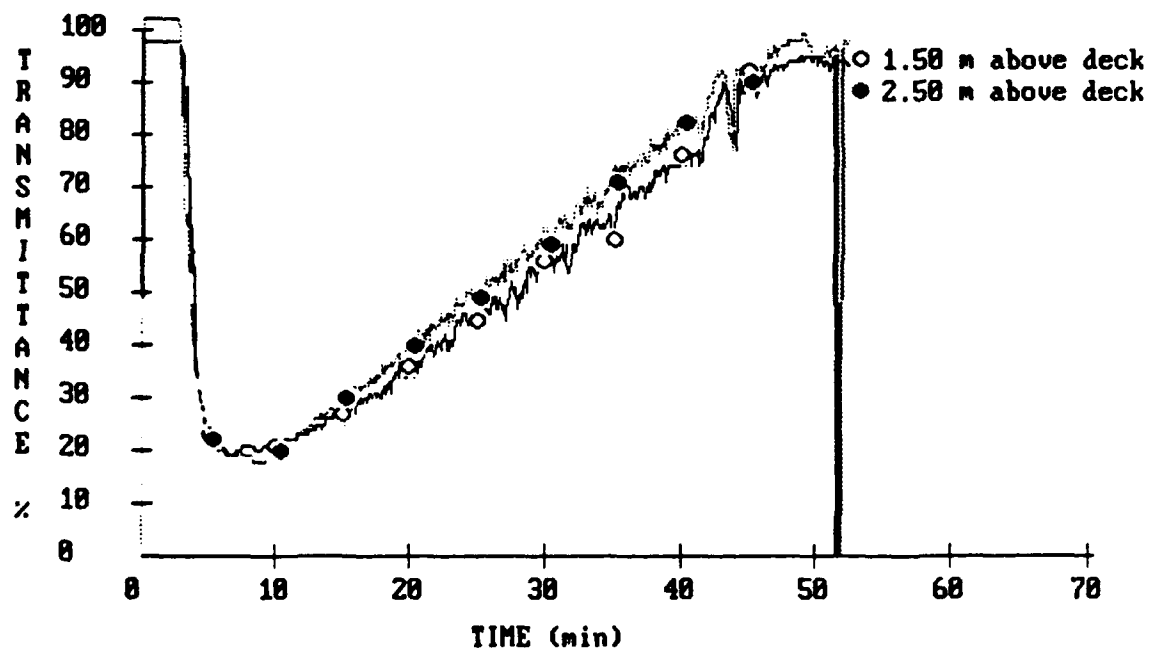


Fig. B-43- Smoke in RICER 1 (2-76-2) during Test # 5

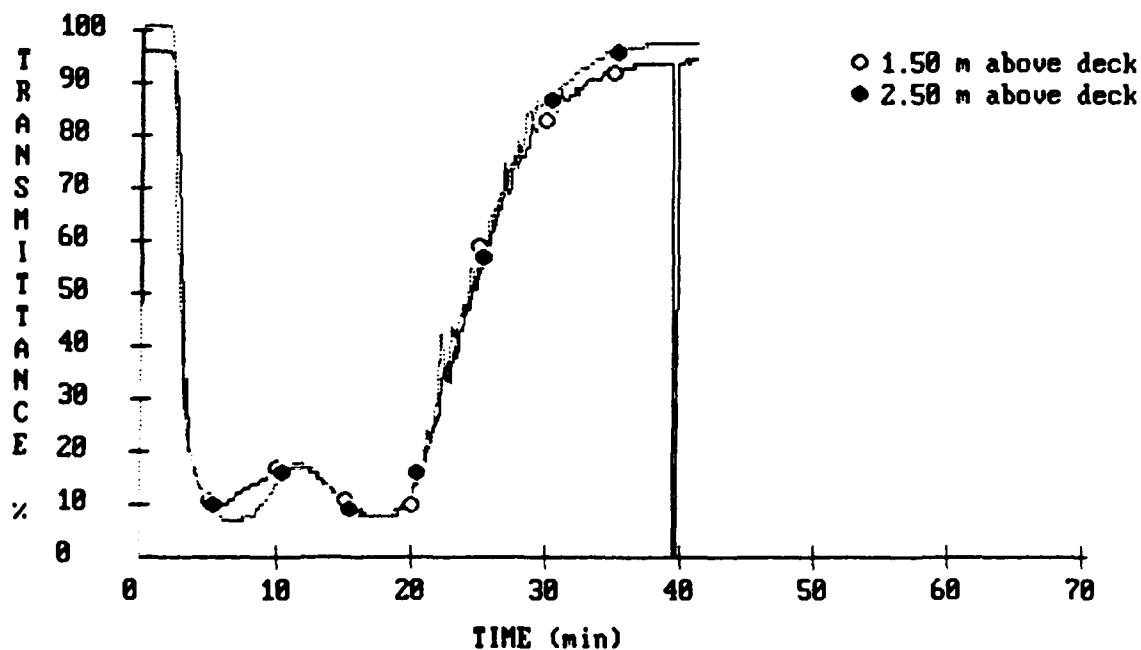
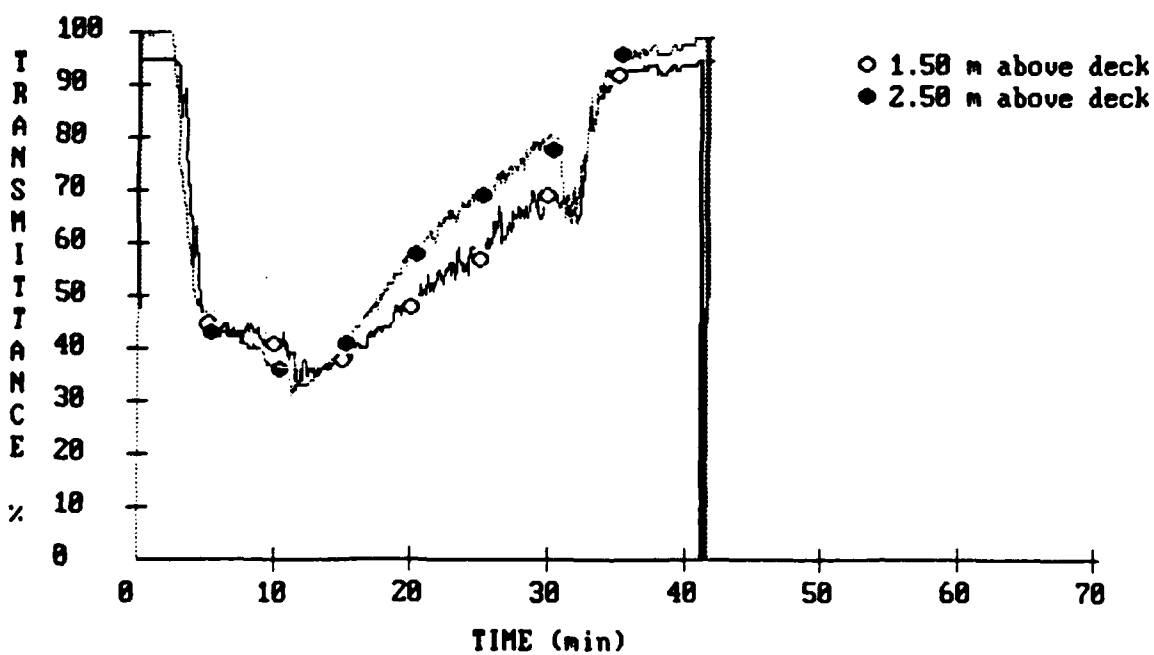
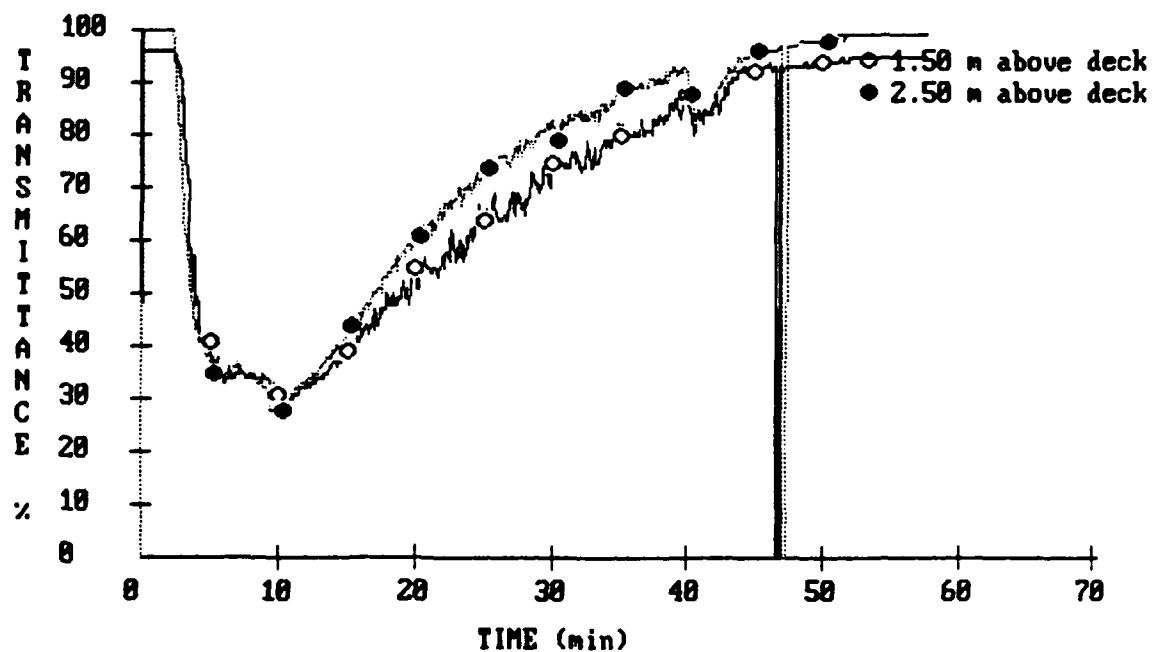


Fig. B-44- Smoke in RICER 1 (2-76-2) during Test # 6



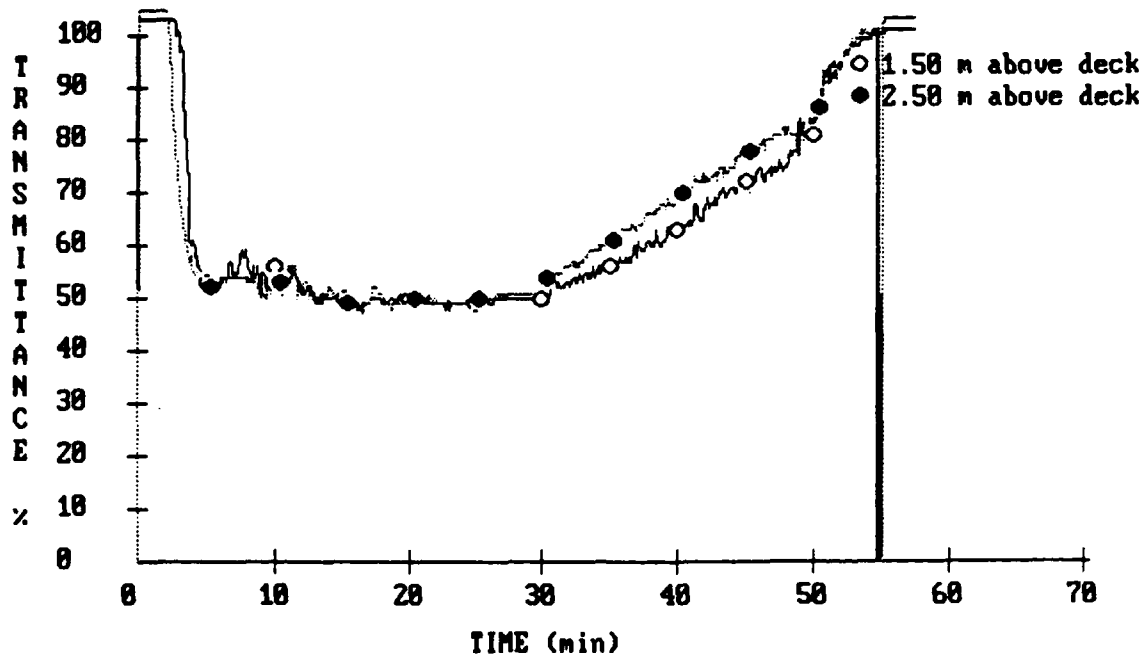


Fig. B-47- Smoke in RICER 1 (2-76-2) during Test # 9

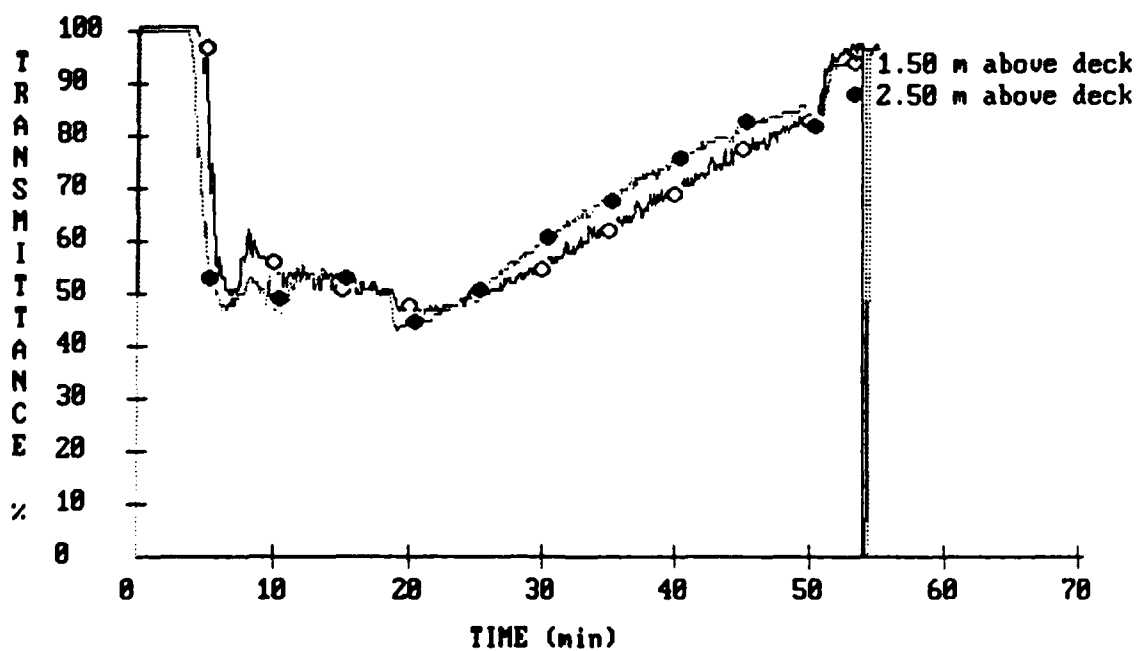


Fig. B-48- Smoke in RICER 1 (2-76-2) during Test # 10

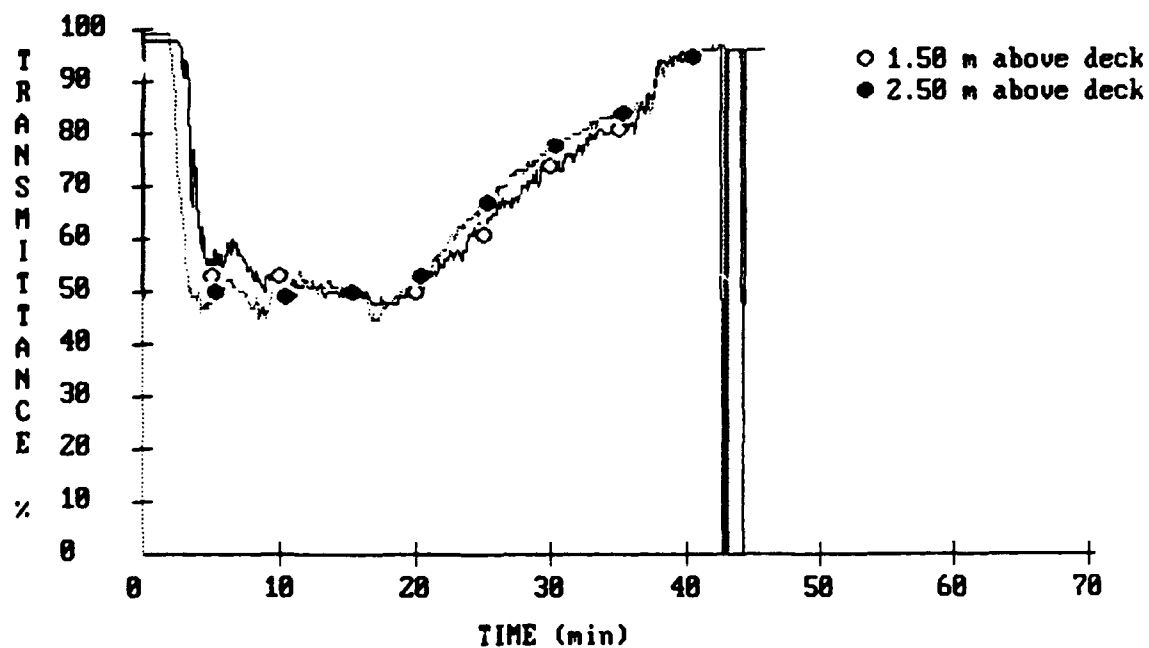


Fig. B-49- Smoke in RICER 1 (2-76-2) during Test # 11

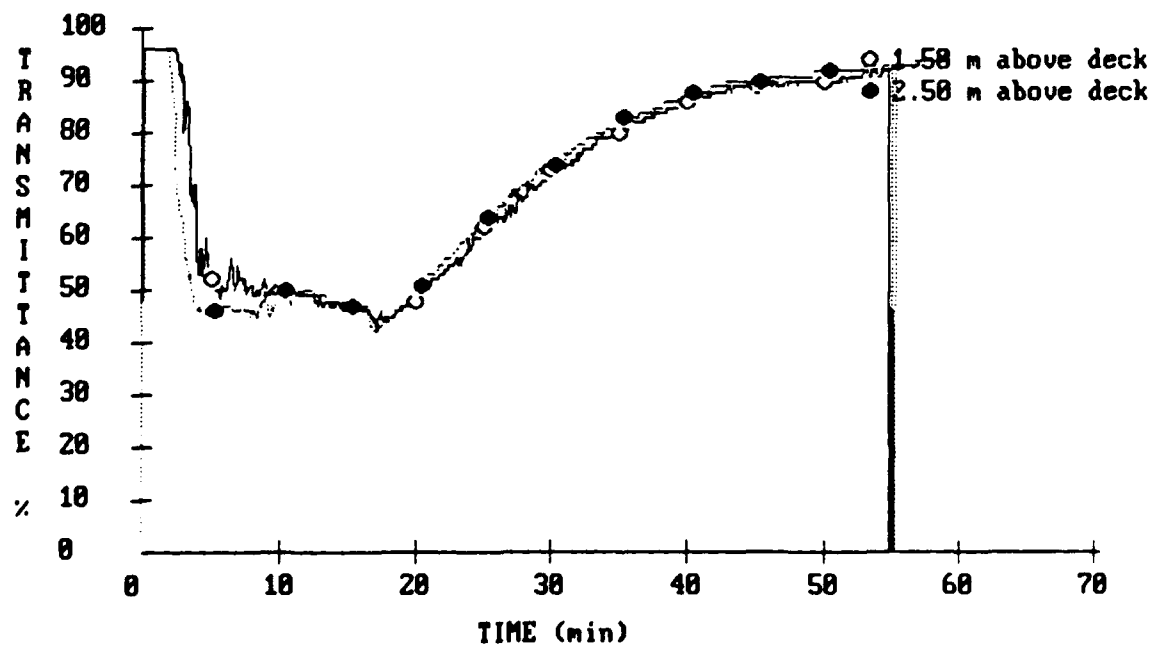


Fig. B-50- Smoke in RICER 1 (2-76-2) during Test # 12

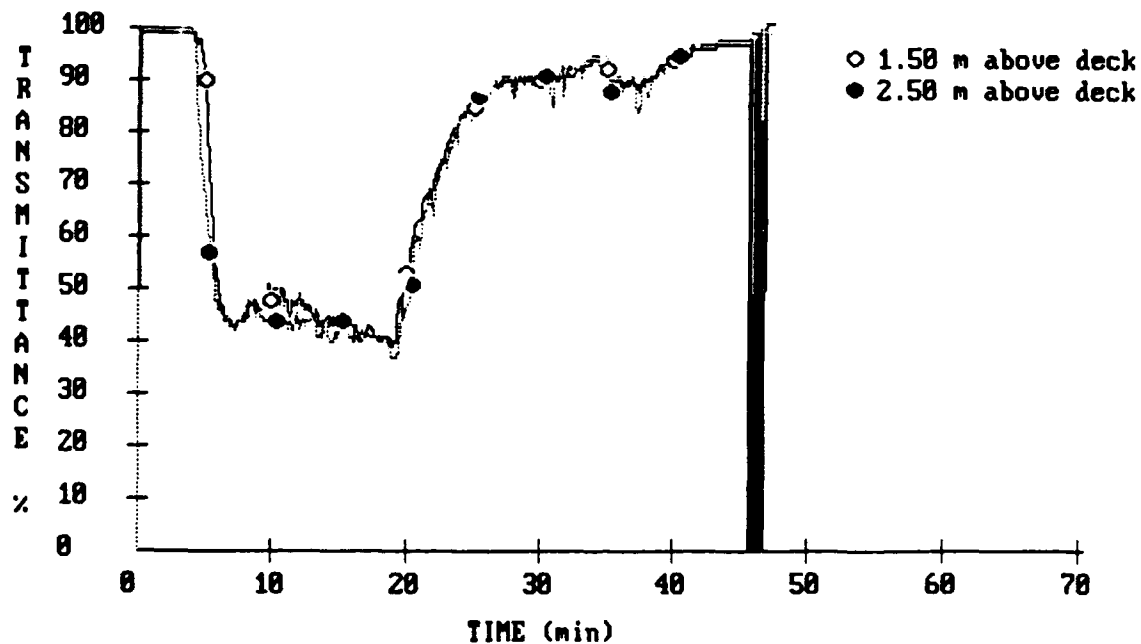


Fig. B-51- Smoke in RICER 1 (2-76-2) during Test # 13

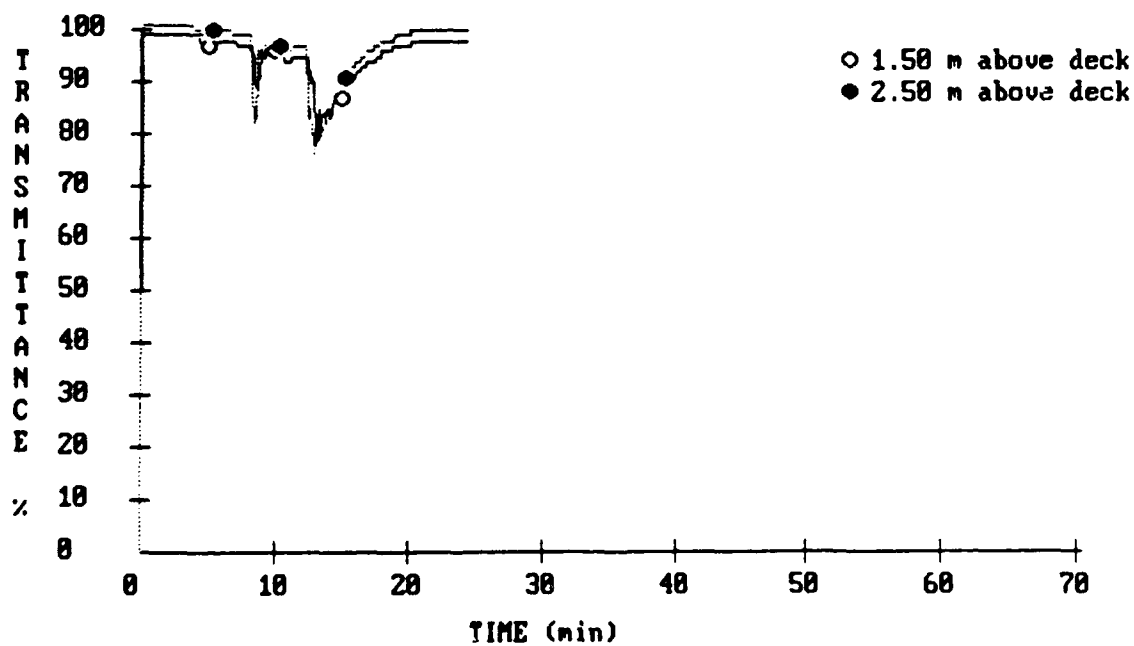


Fig. B-52- Smoke in RICER 1 (2-76-2) during Test # 14

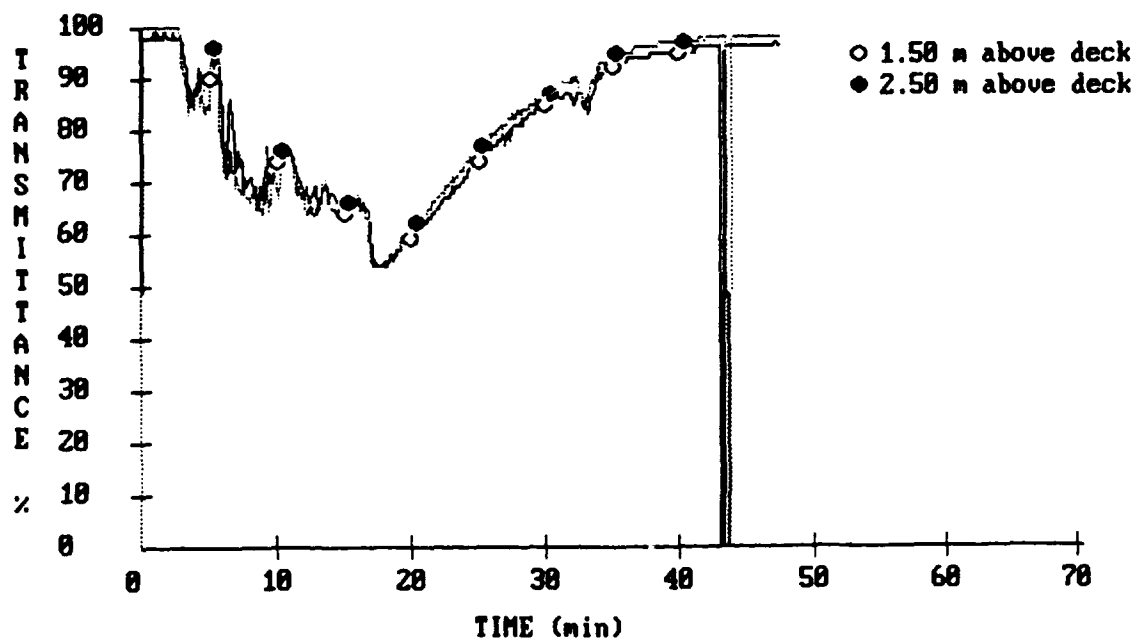


Fig. B-53- Smoke in RICER 1 (2-76-2) during Test # 15

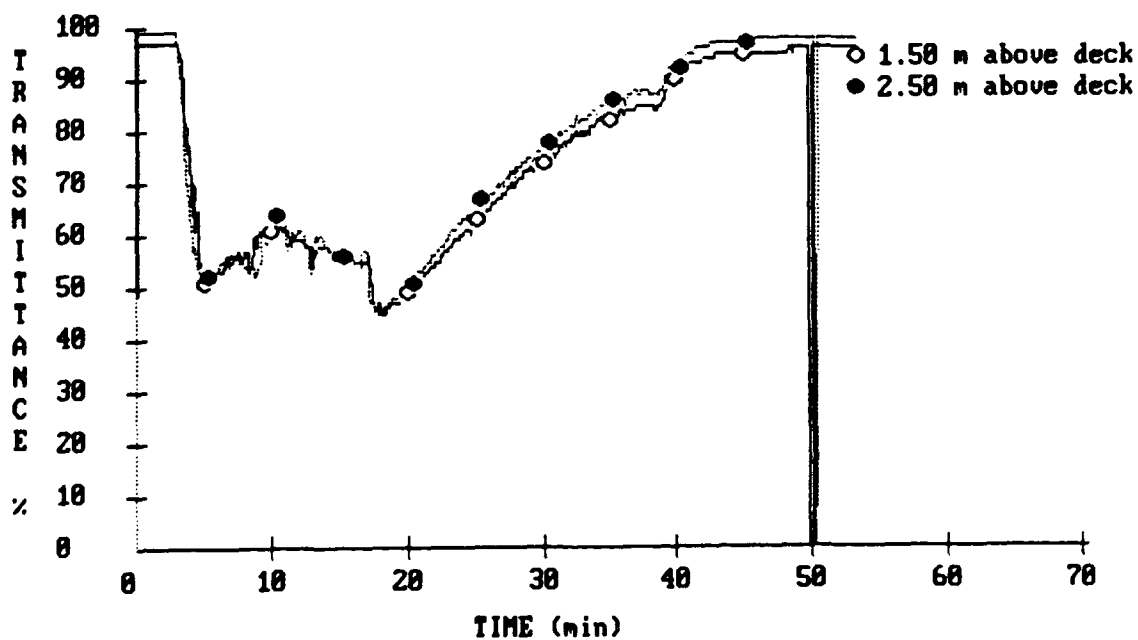


Fig. B-54- Smoke in RICER 1 (2-76-2) during Test # 16

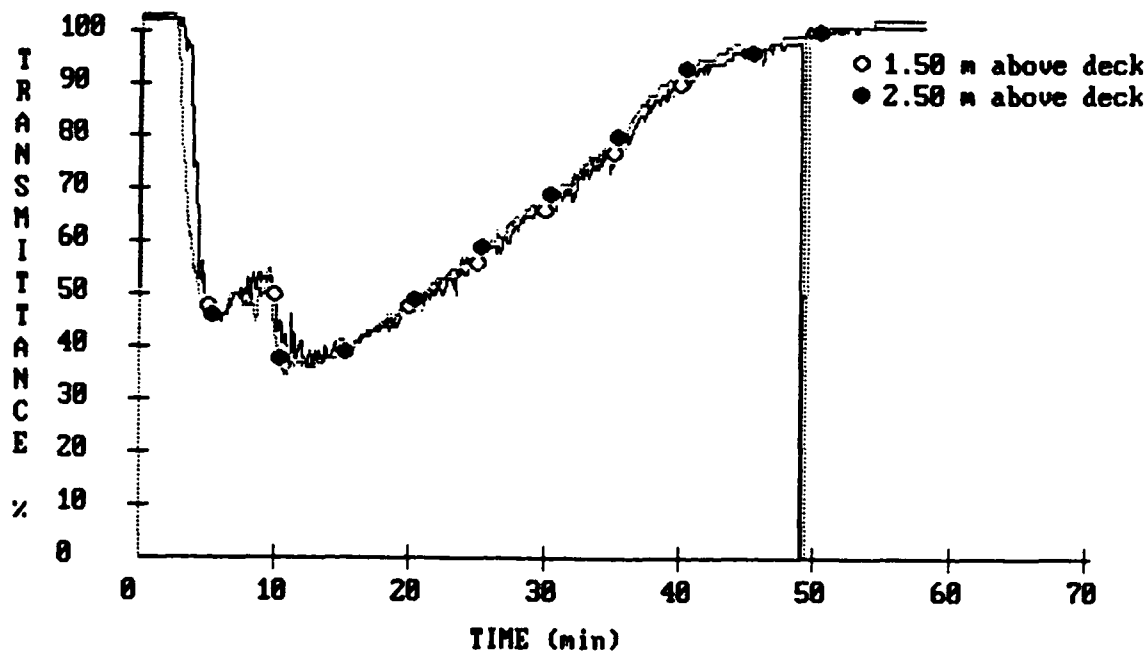


Fig. B-55- Smoke in RICER 1 (2-76-2) during Test # 17

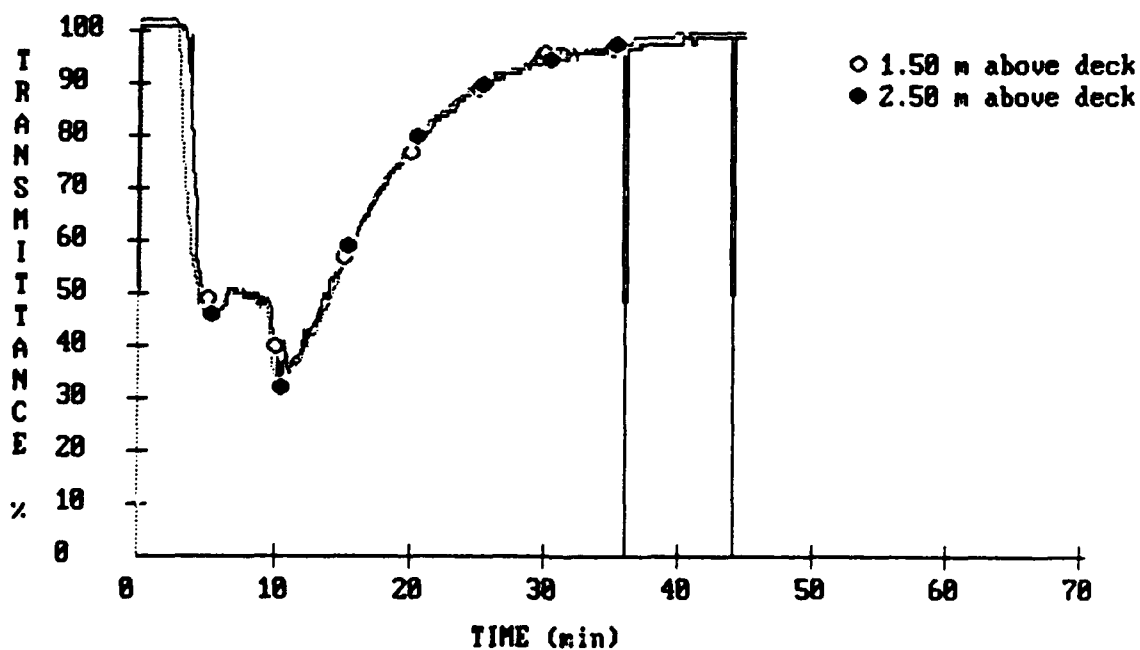


Fig. B-56- Smoke in RICER 1 (2-76-2) during Test # 18



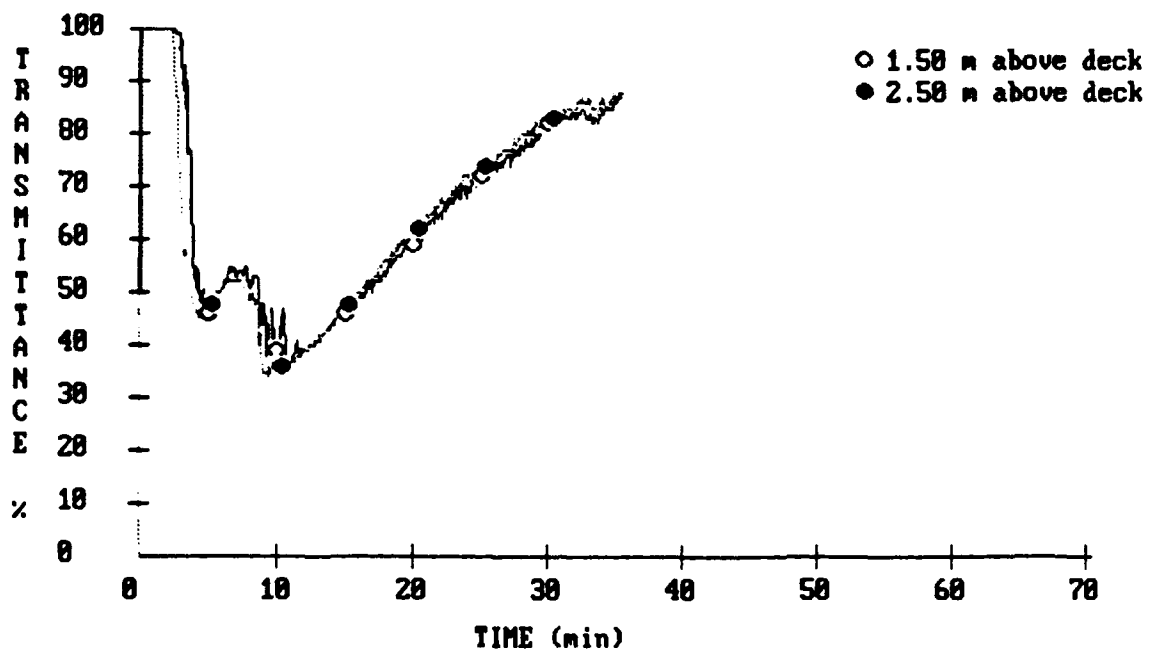


Fig. B-57- Smoke in RICER 1 (2-76-2) during Test # 19

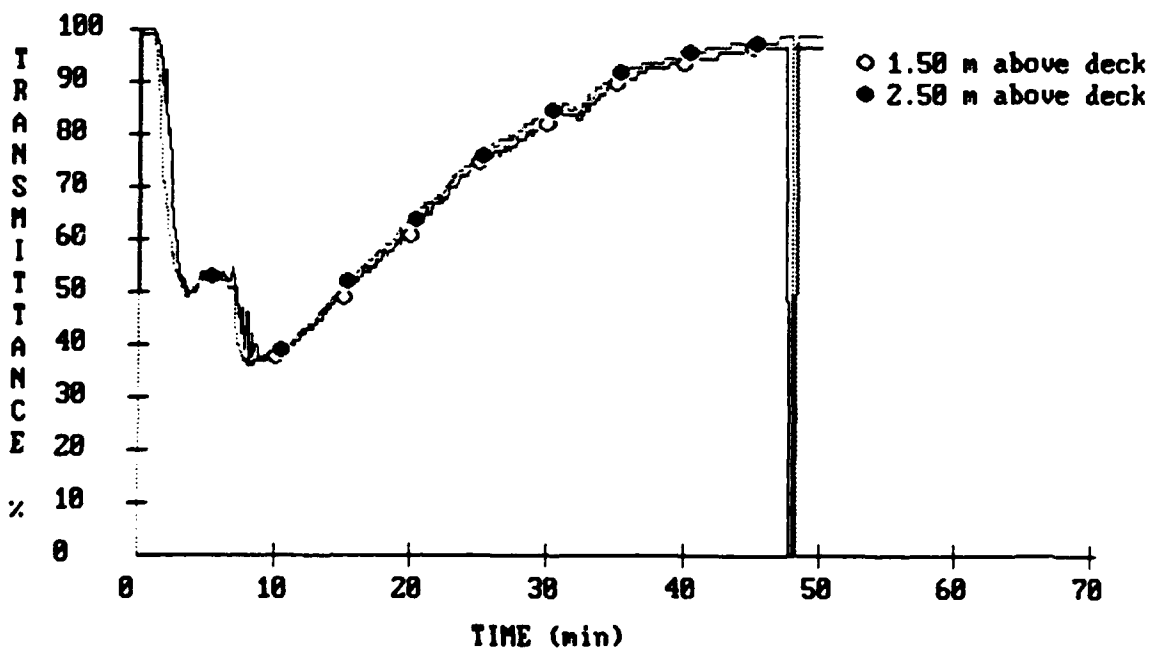


Fig. B-58- Smoke in RICER 1 (2-76-2) during Test # 20

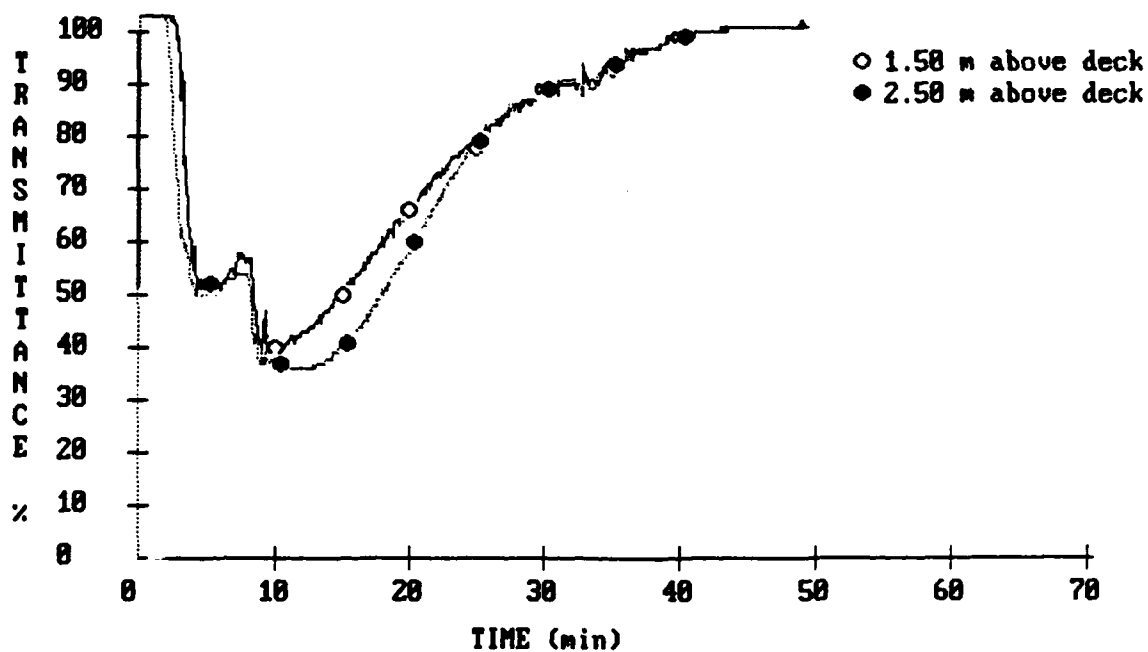


Fig. B-59- Smoke in RICER 1 (2-76-2) during Test # 21

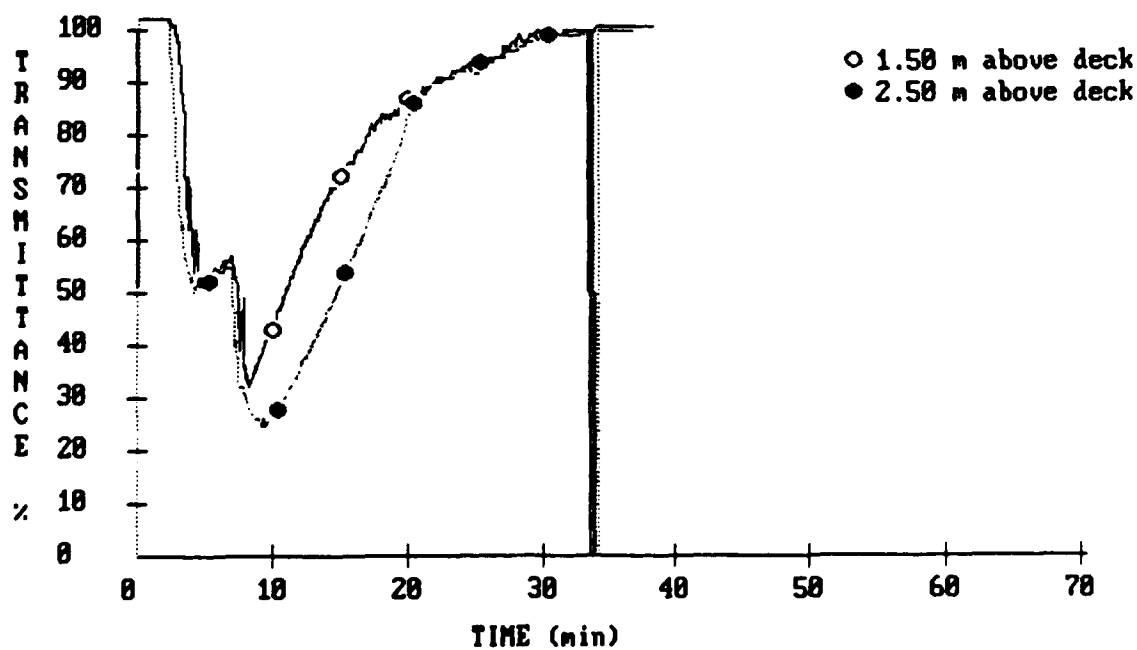


Fig. B-60- Smoke in RICER 1 (2-76-2) during Test # 22

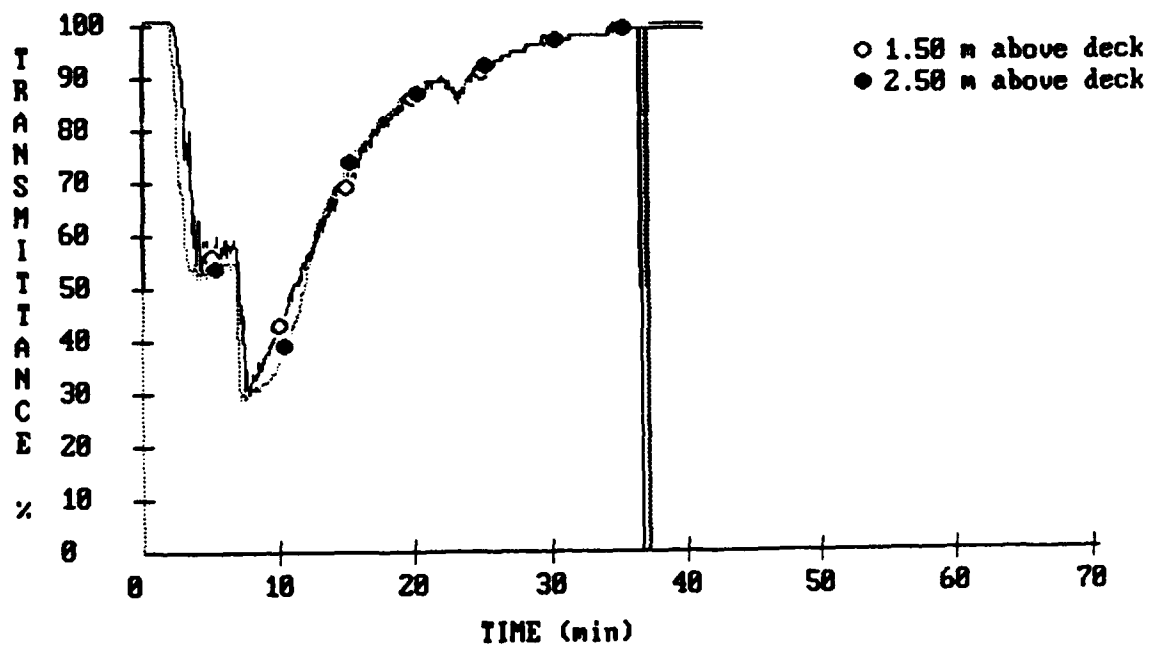


Fig. B-61- Smoke in RICER 1 (2-76-2) during Test # 23

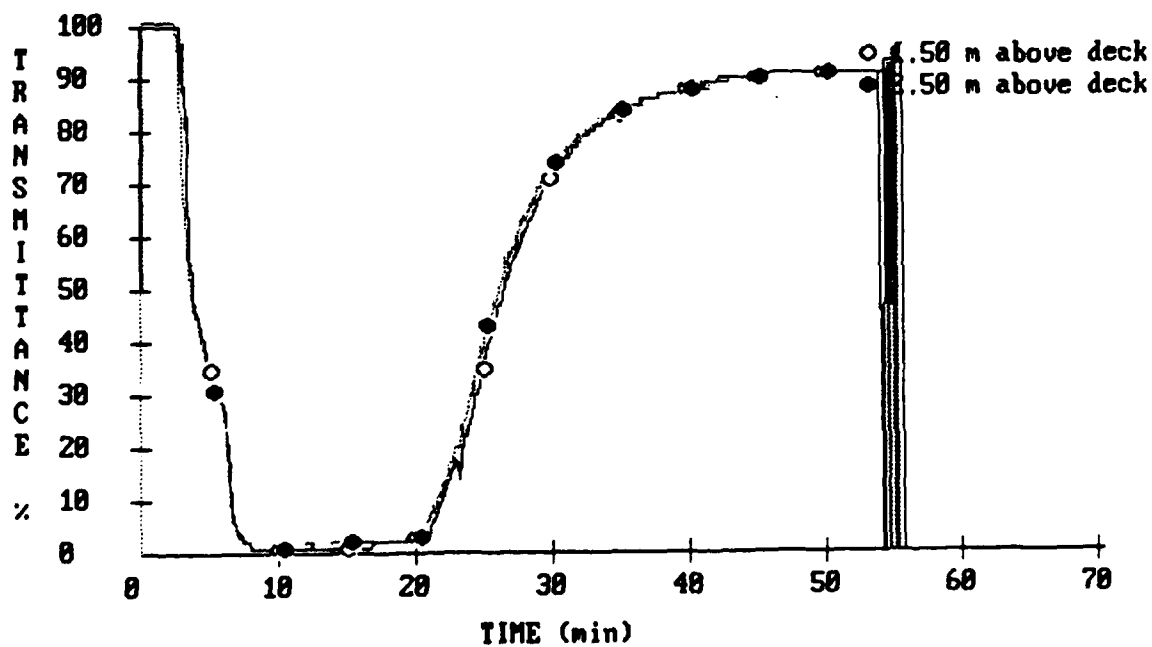


Fig. B-62- Smoke in RICER 1 (2-76-2) during Test # 24

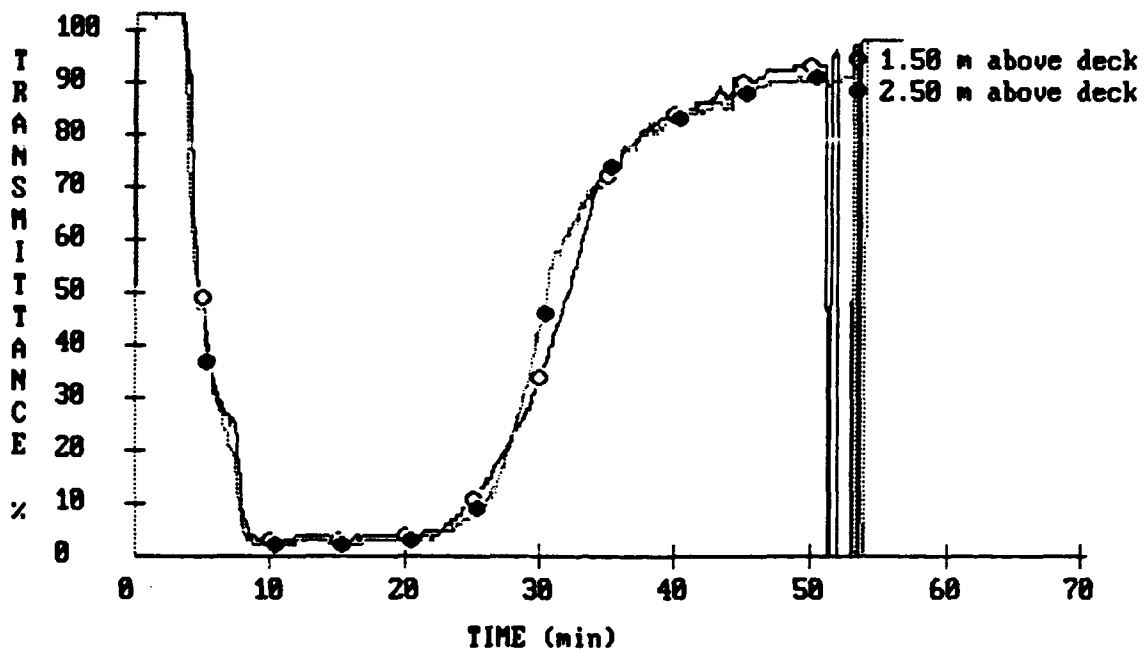


Fig. B-63- Smoke in RICER 1 (2-76-2) during Test # 25

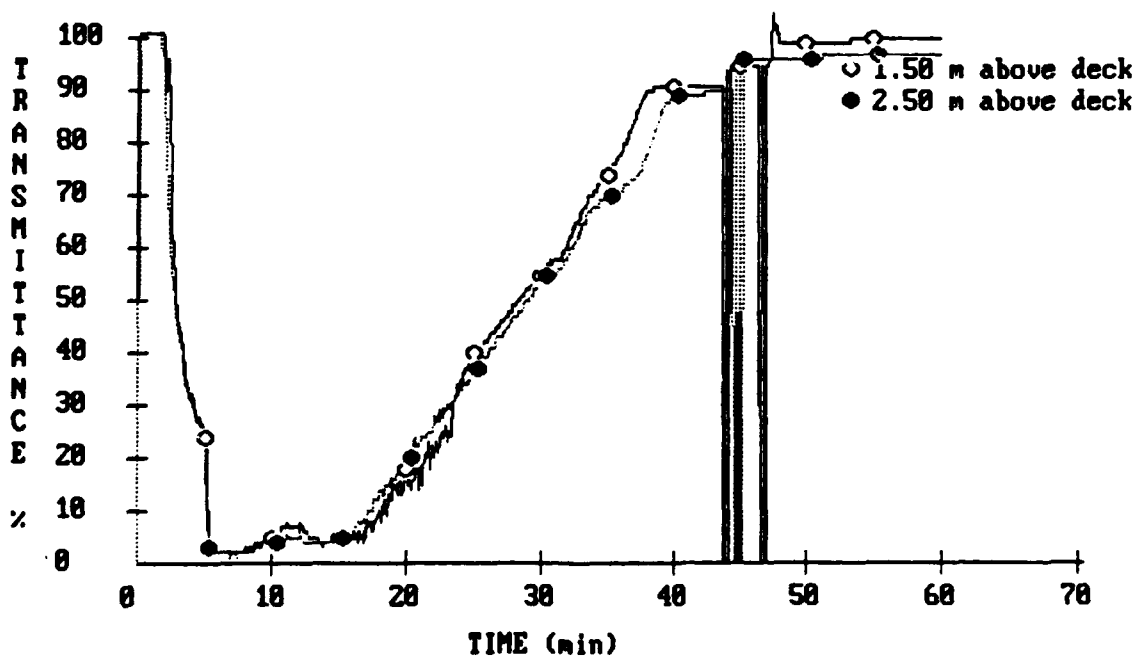


Fig. B-64- Smoke in RICER 1 (2-76-2) during Test # 26

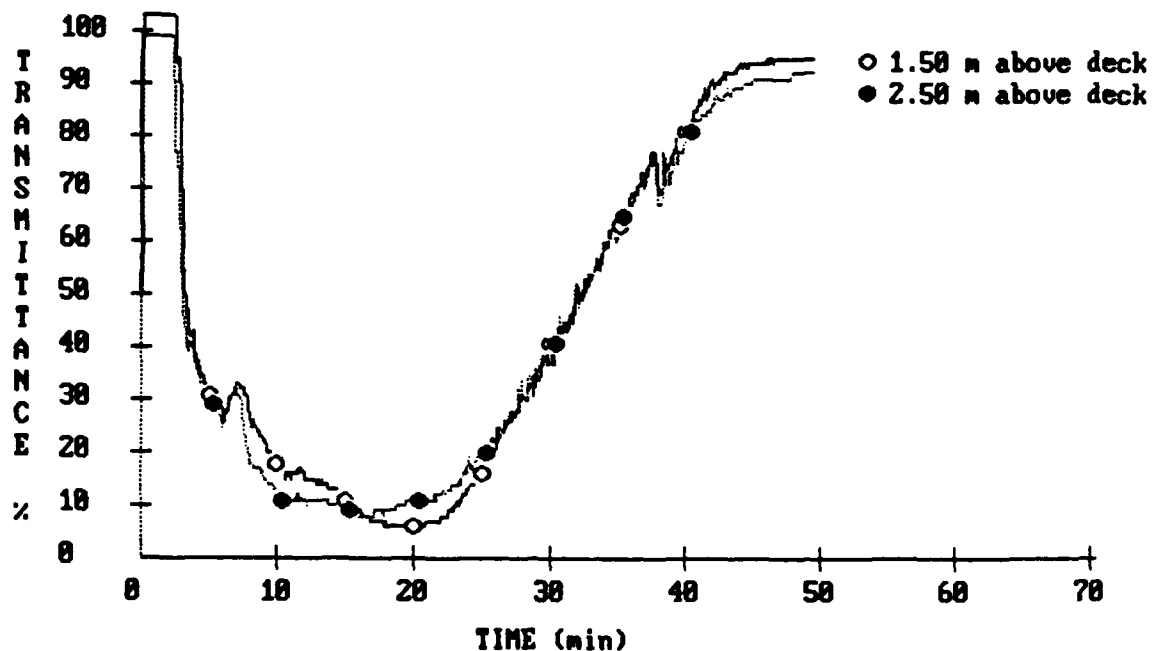


Fig. B-65- Smoke in RICER 1 (2-76-2) during Test # 27

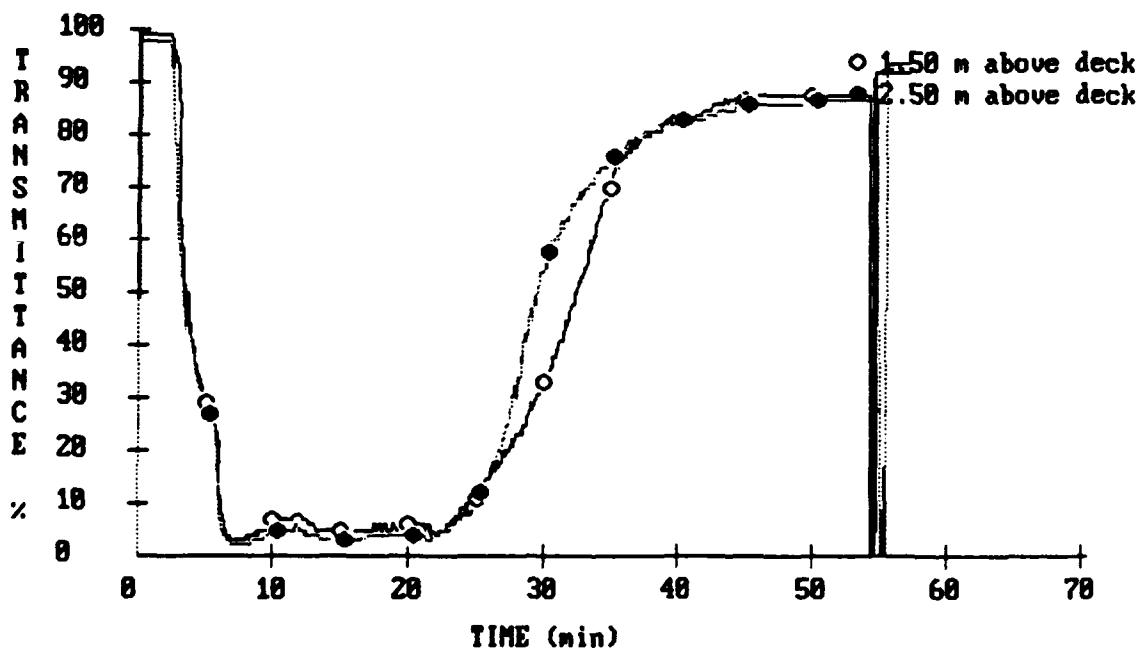


Fig. B-66- Smoke in RICER 1 (2-76-2) during Test # 28

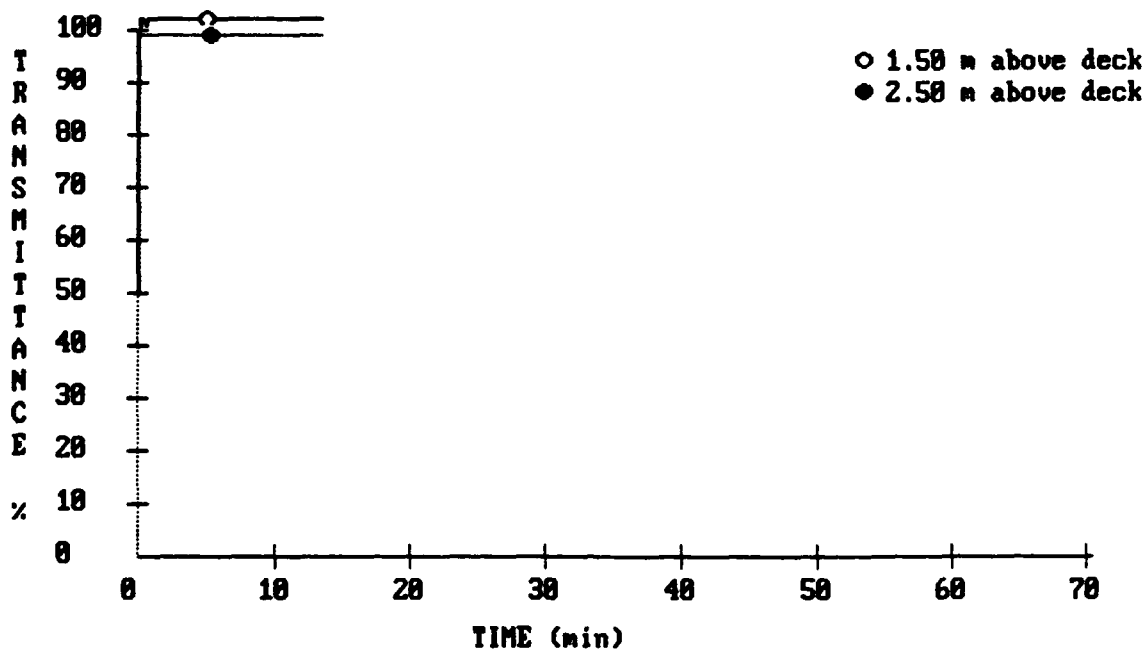


Fig. B-67- Smoke in RICER 1 (2-76-2) during Test # 29

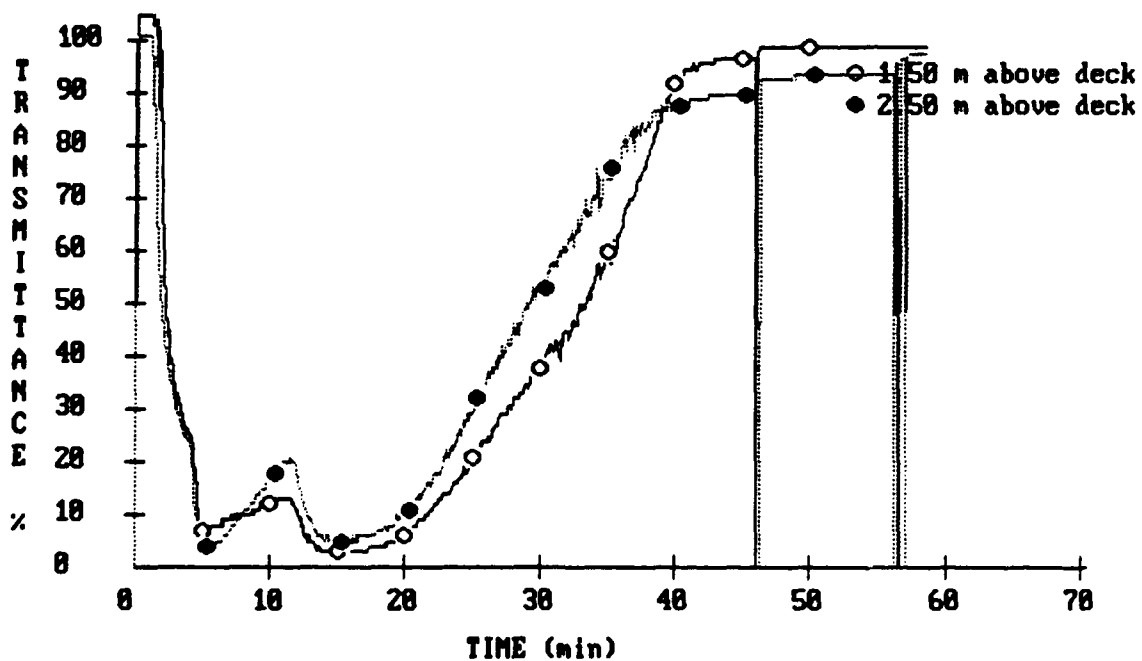


Fig. B-68- Smoke in RICER 1 (2-76-2) during Test # 30

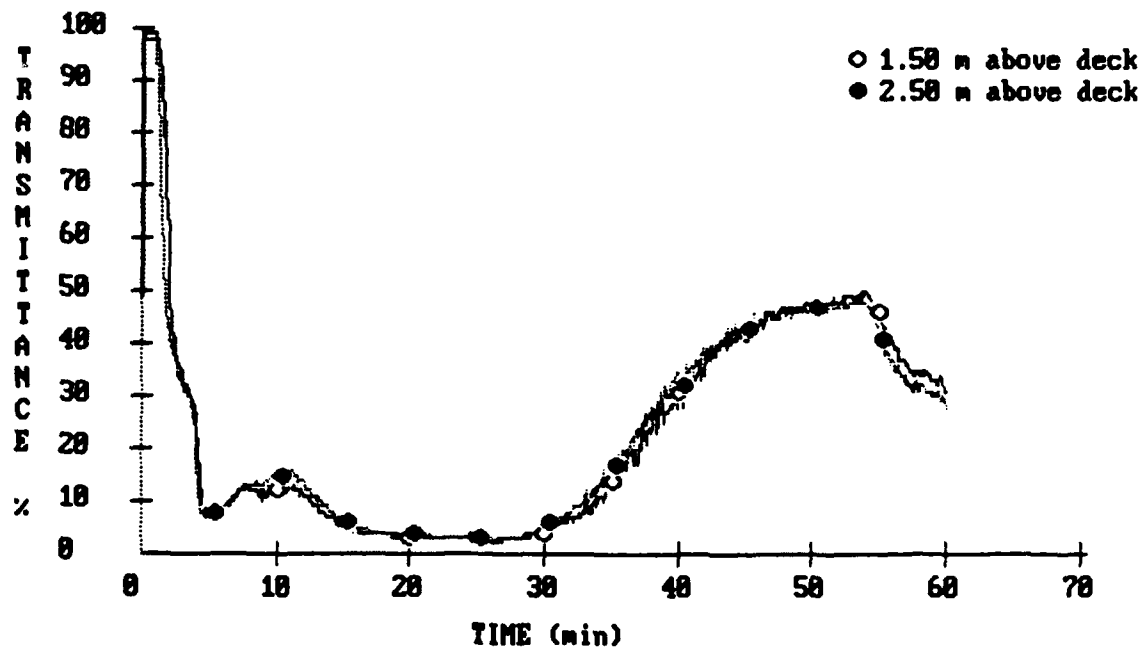


Fig. B-69- Smoke in RICER 1 (2-76-2) during Test # 31

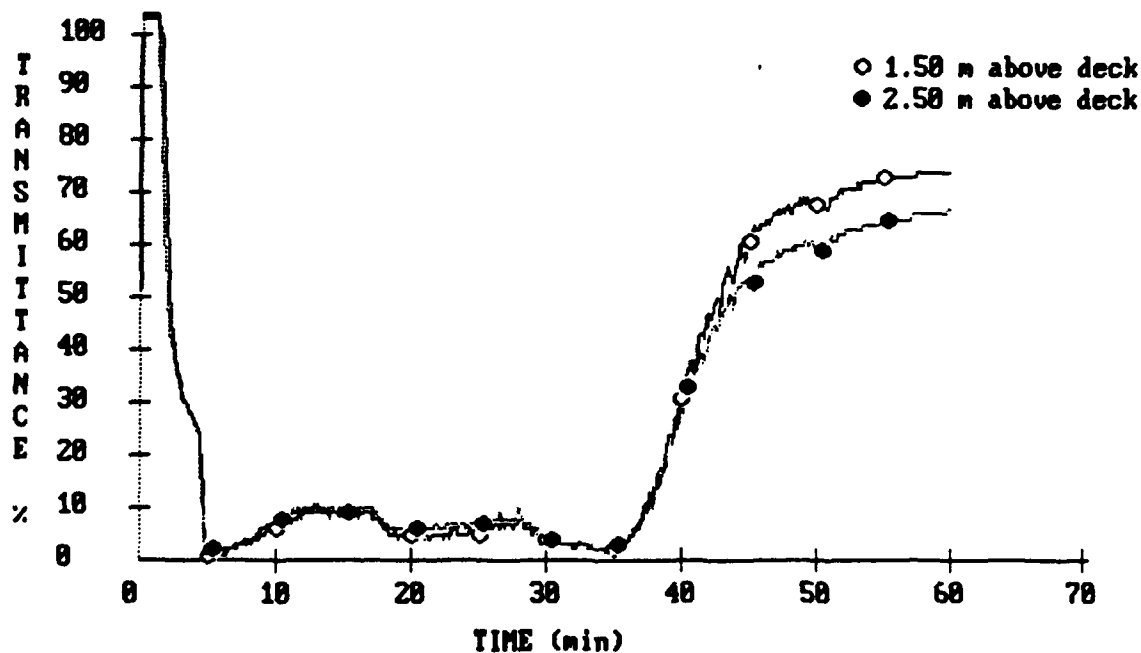


Fig. B-70- Smoke in RICER 1 (2-76-2) during Test # 32

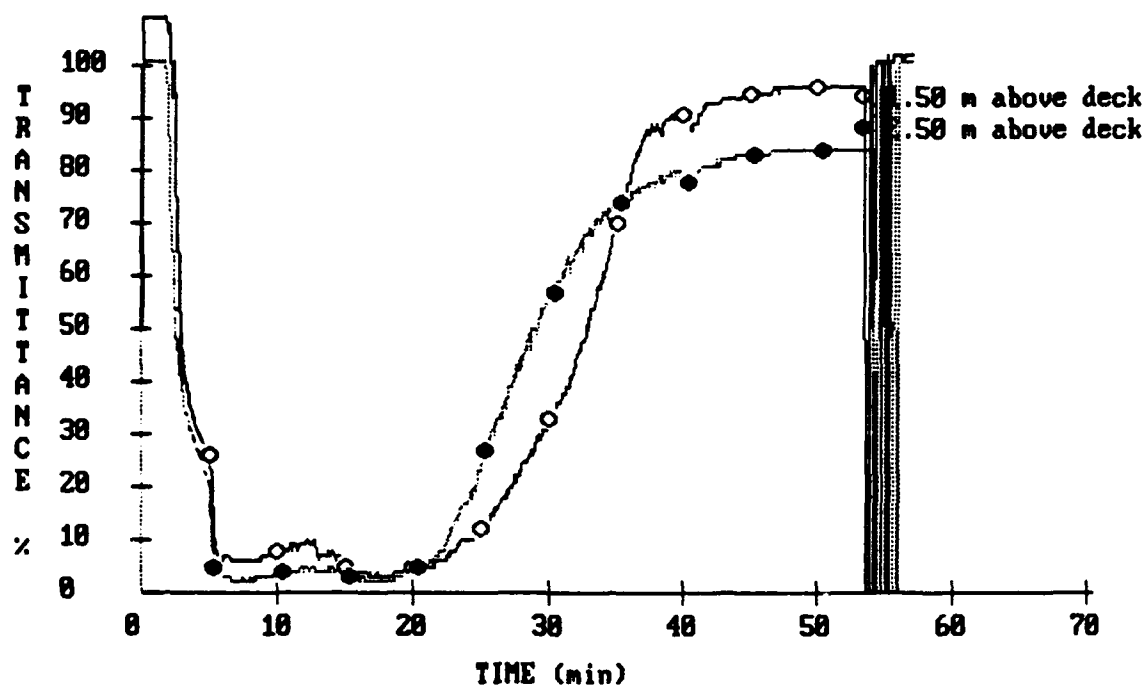


Fig. B-71- Smoke in RICER 1 (2-76-2) during Test # 33

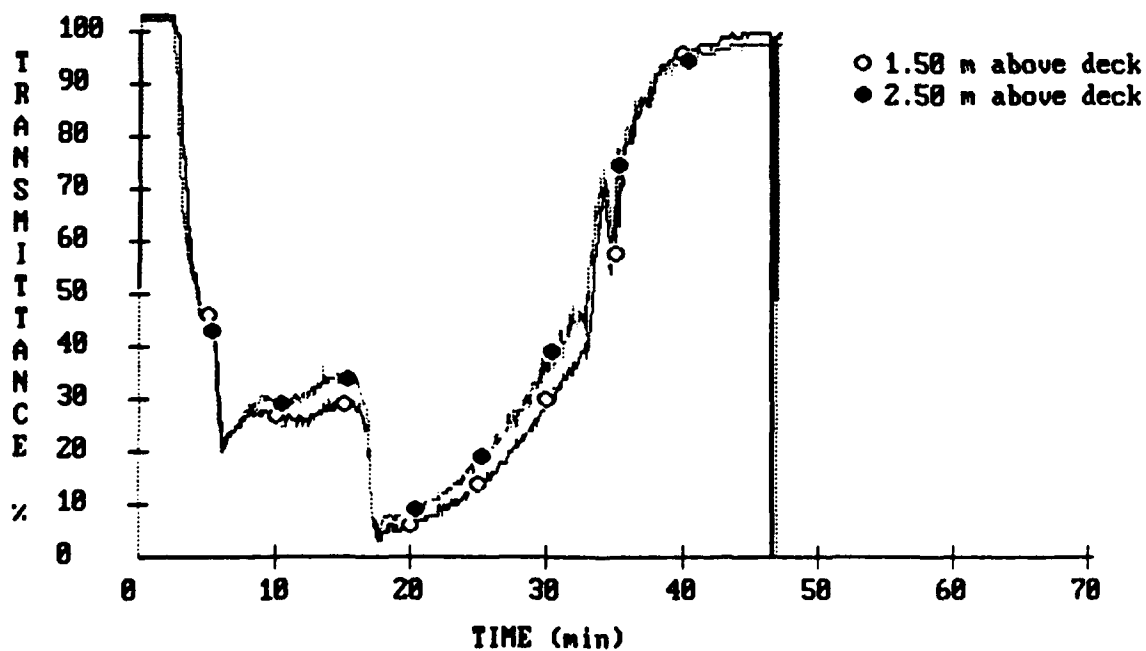


Fig. B-72- Smoke in RICER 1 (2-76-2) during Test # 34



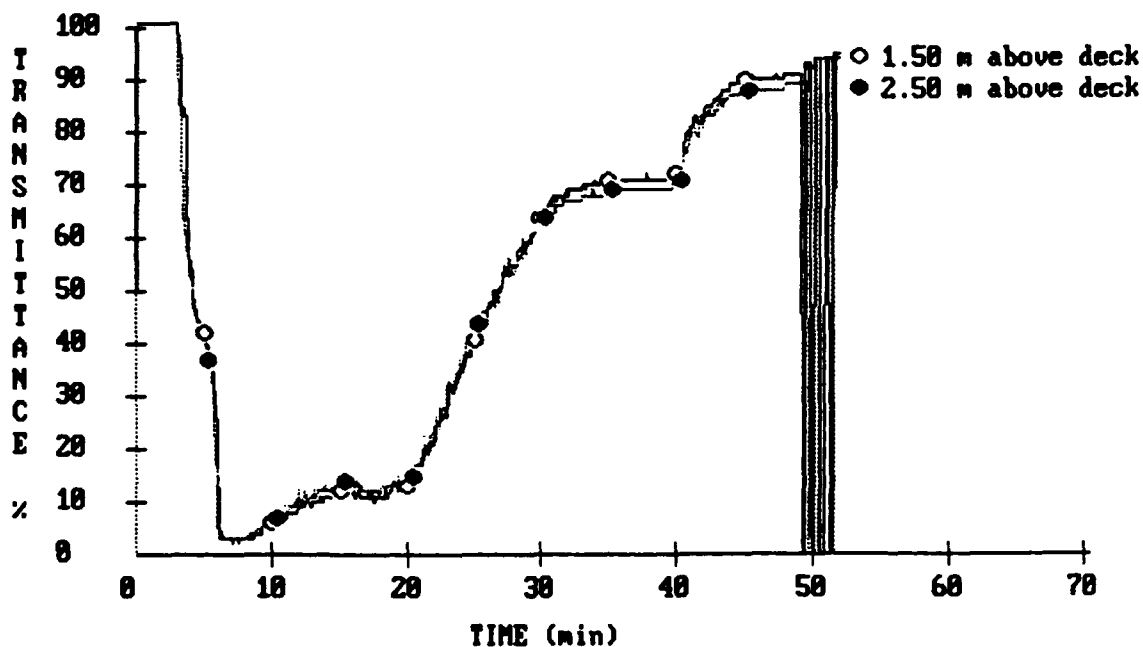


Fig. B-73- Smoke in RICER 1 (2-76-2) during Test # 35

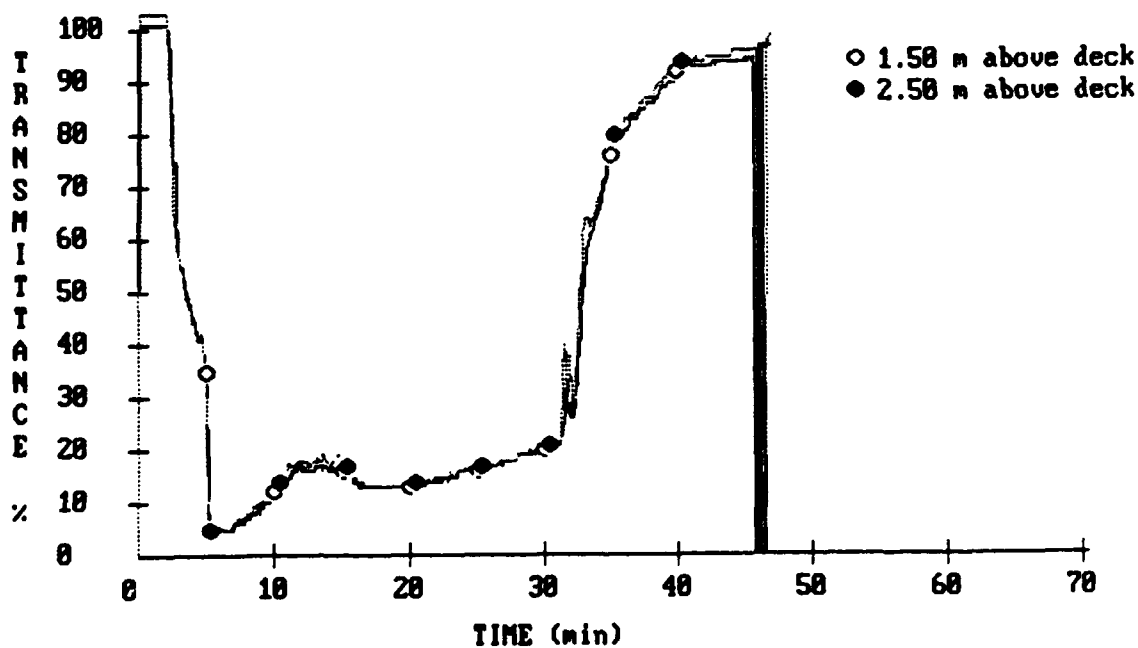


Fig. B-74- Smoke in RICER 1 (2-76-2) during Test # 36

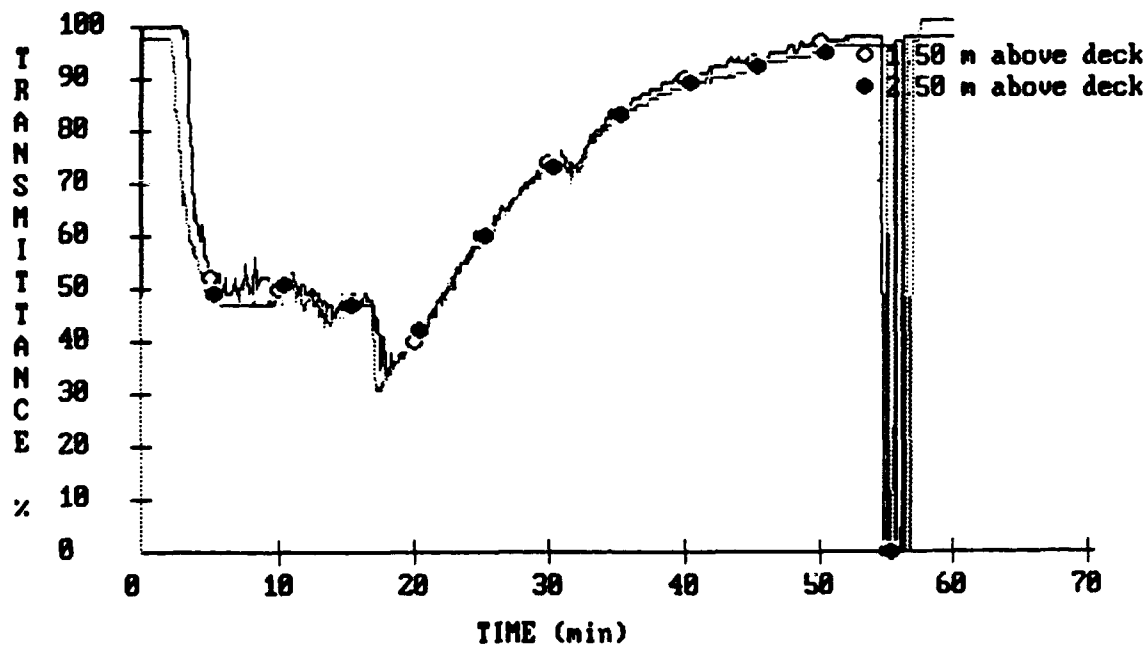


Fig. B-75- Smoke in RICER 1 (2-76-2) during Test # 37

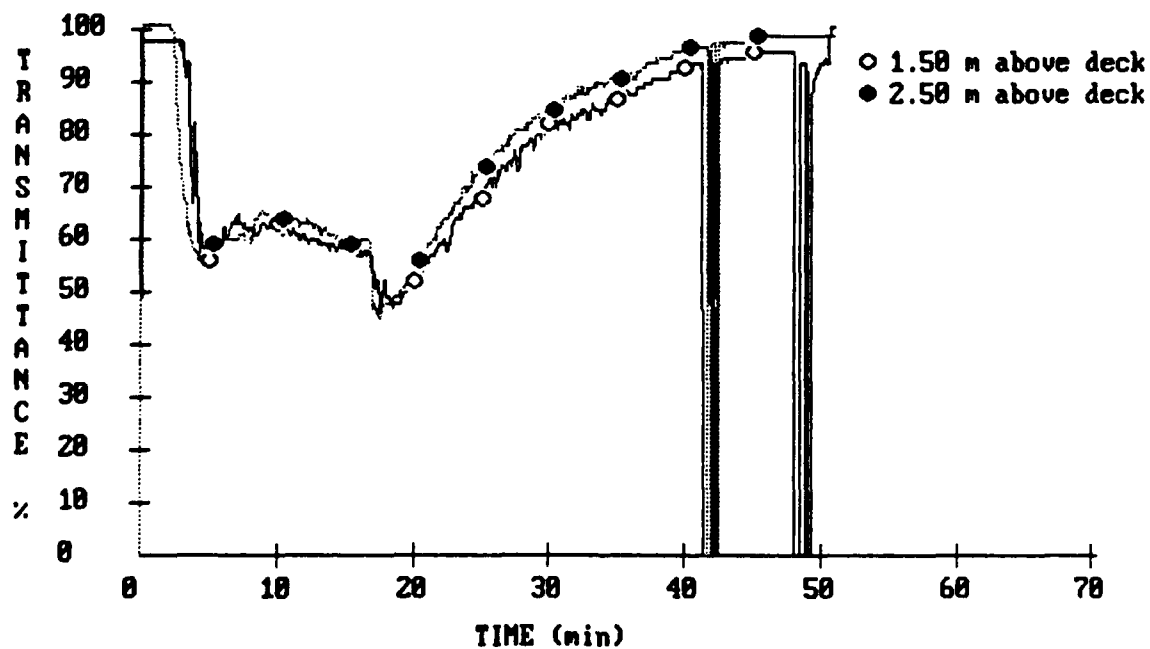


Fig. B-76- Smoke in RICER 1 (2-76-2) during Test # 38

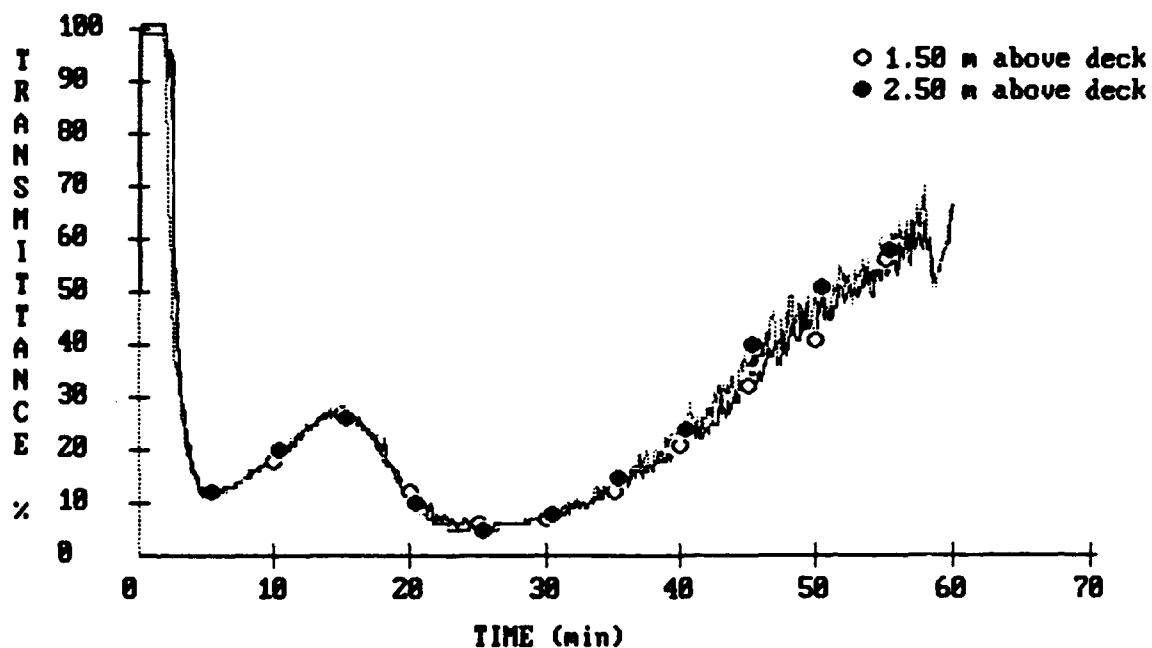


Fig. B-77- Smoke in RICER 1 (2-76-2) during Test # 39

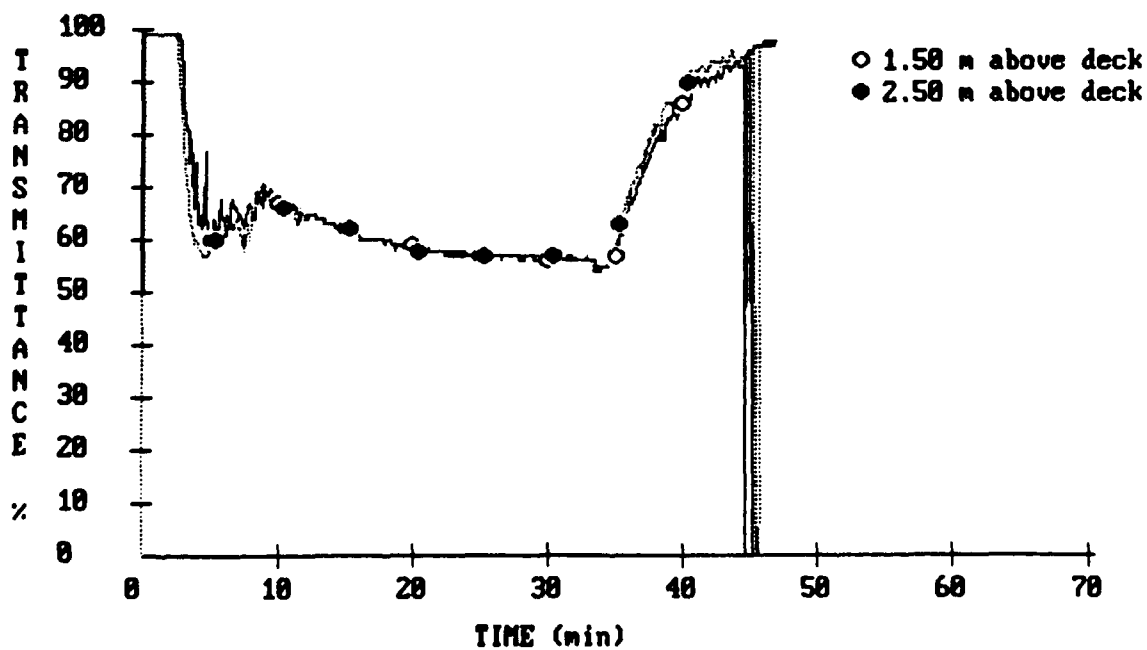


Fig. B-78- Smoke in RICER 1 (2-76-2) during Test # 40

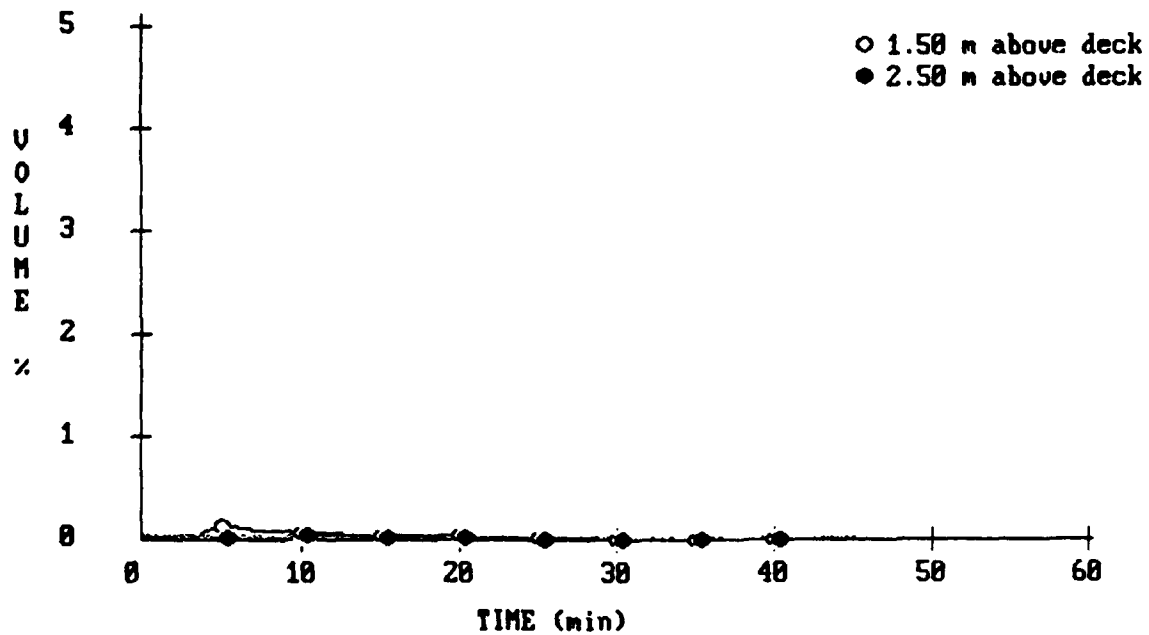


Fig. B-79- CO concentration in BERTHING 1 (3-76-2) during Test # 2

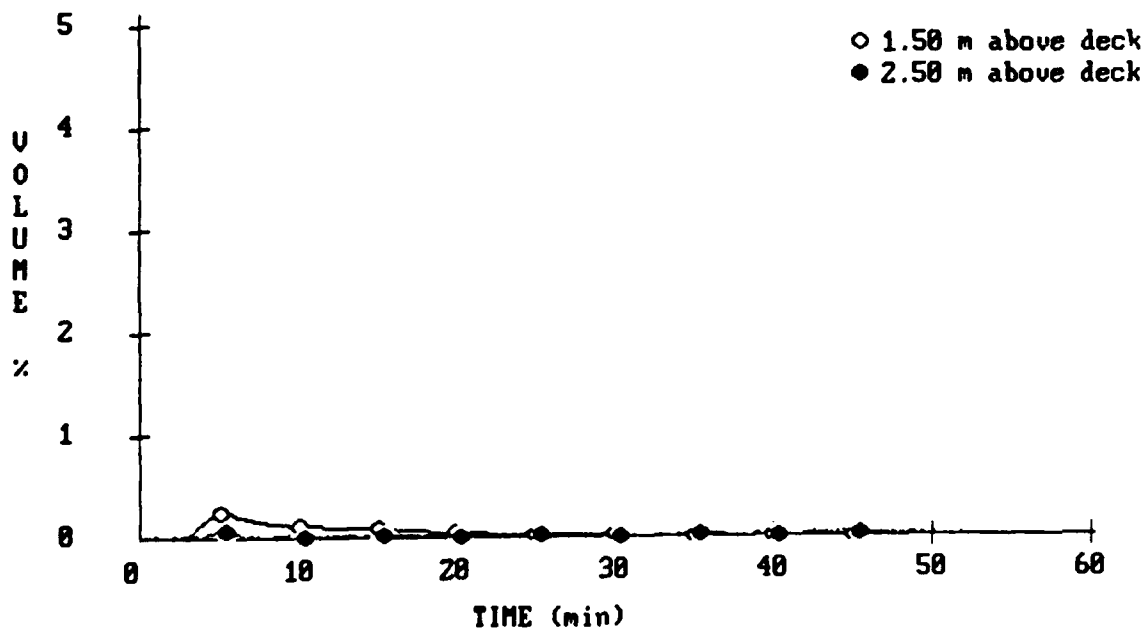


Fig. B-80- CO concentration in BERTHING 1 (3-76-2) during Test # 3

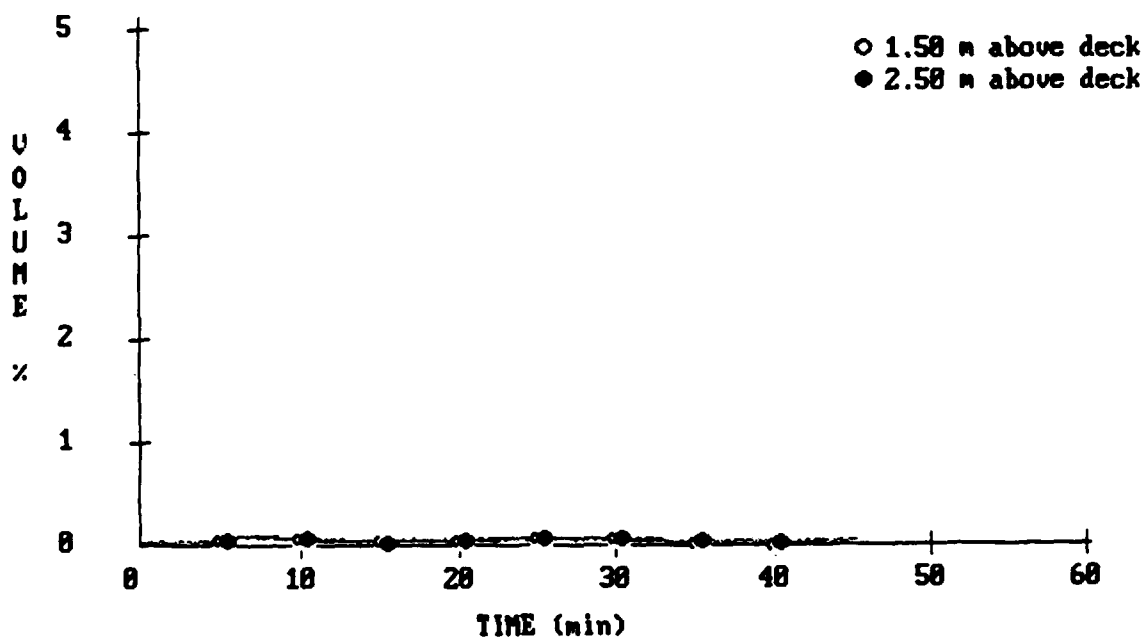


Fig. B-81- CO concentration in BERTHING 1 (3-76-2) during Test # 4

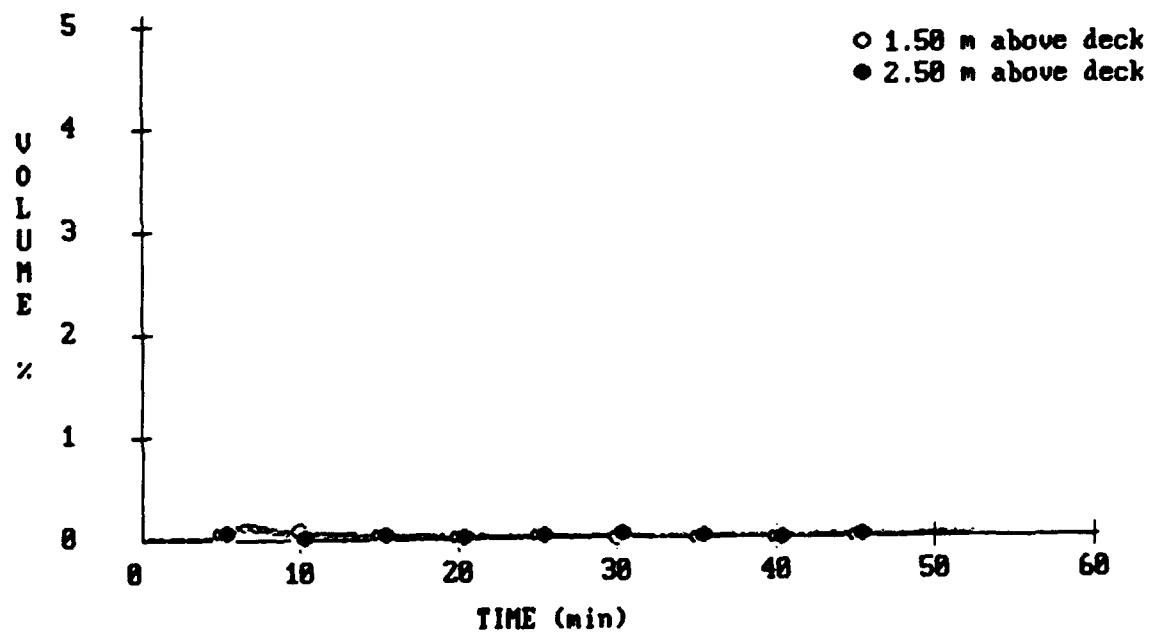


Fig. B-82- CO concentration in BERTHING 1 (3-76-2) during Test # 5

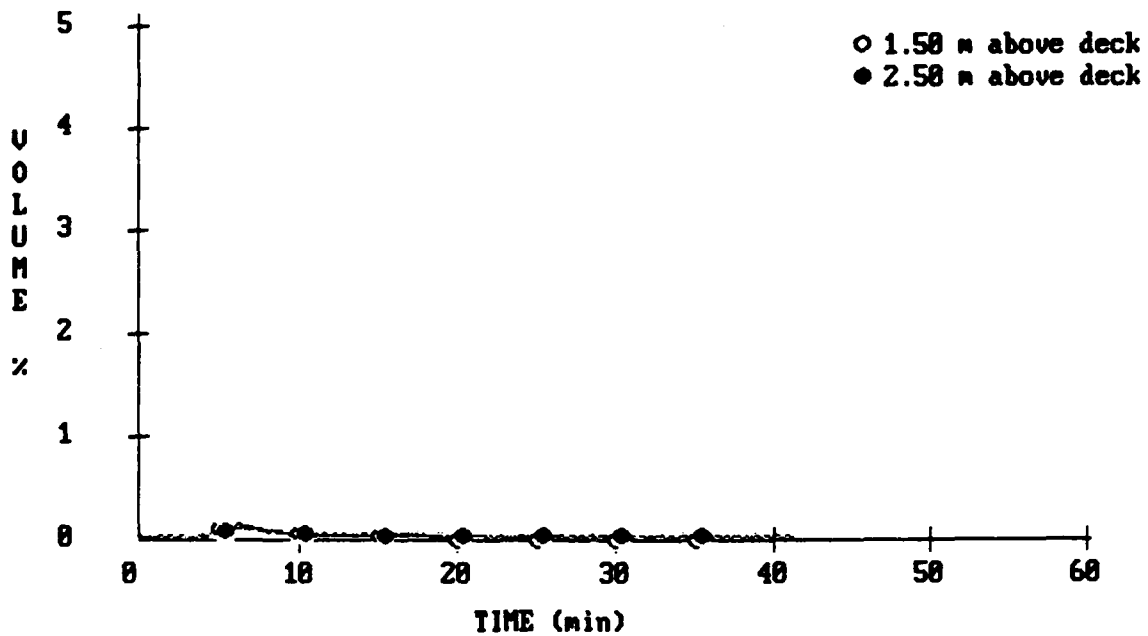


Fig. B-83- CO concentration in BERTHING 1 (3-76-2) during Test # 6

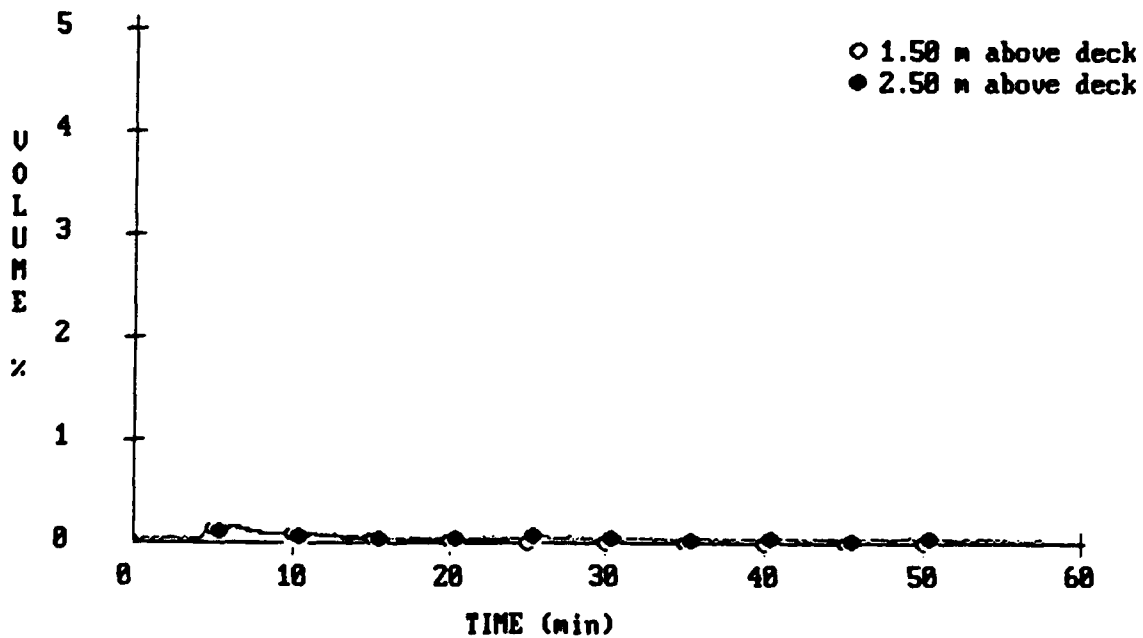


Fig. B-84- CO concentration in BERTHING 1 (3-76-2) during Test # 7

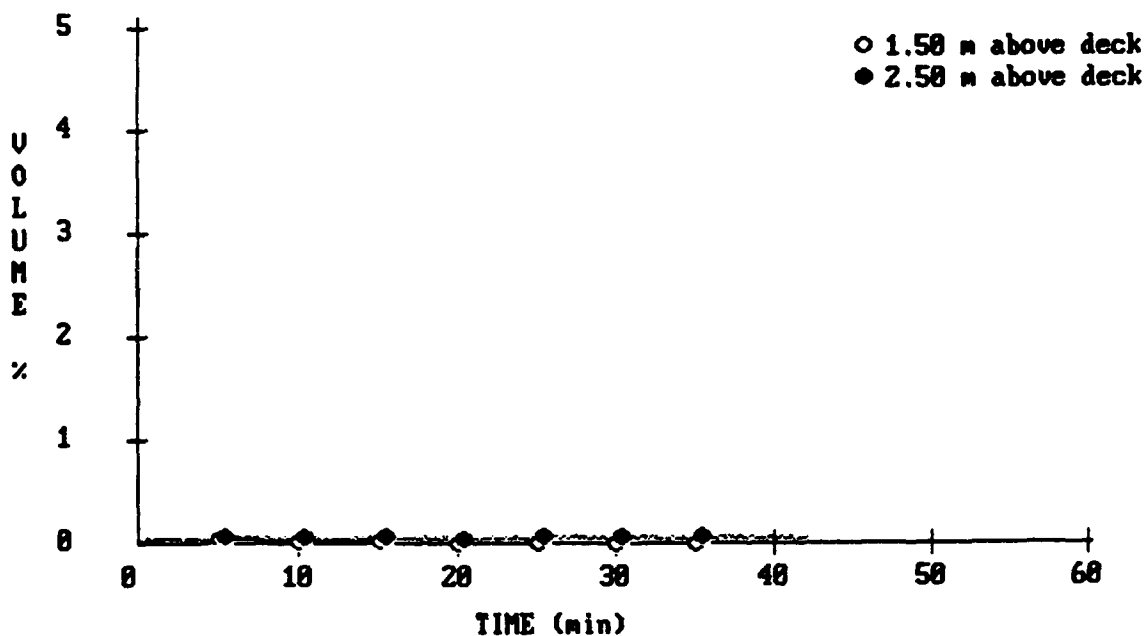


Fig. B-85- CO concentration in BERTHING 1 (3-76-2) during Test # 8

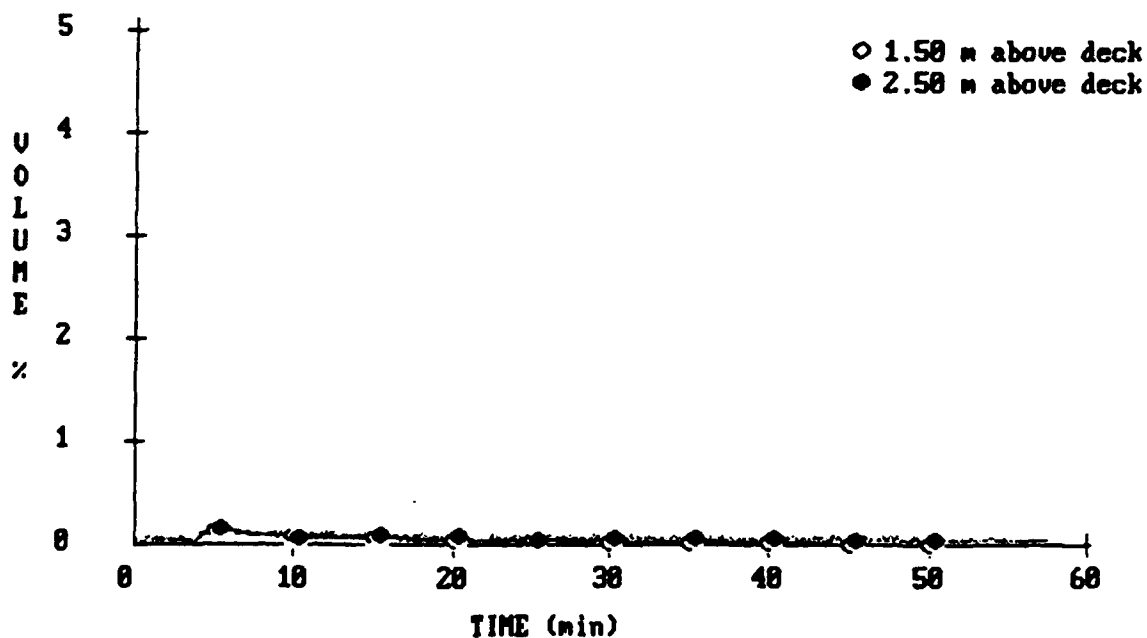


Fig. B-86- CO concentration in BERTHING 1 (3-76-2) during Test # 9

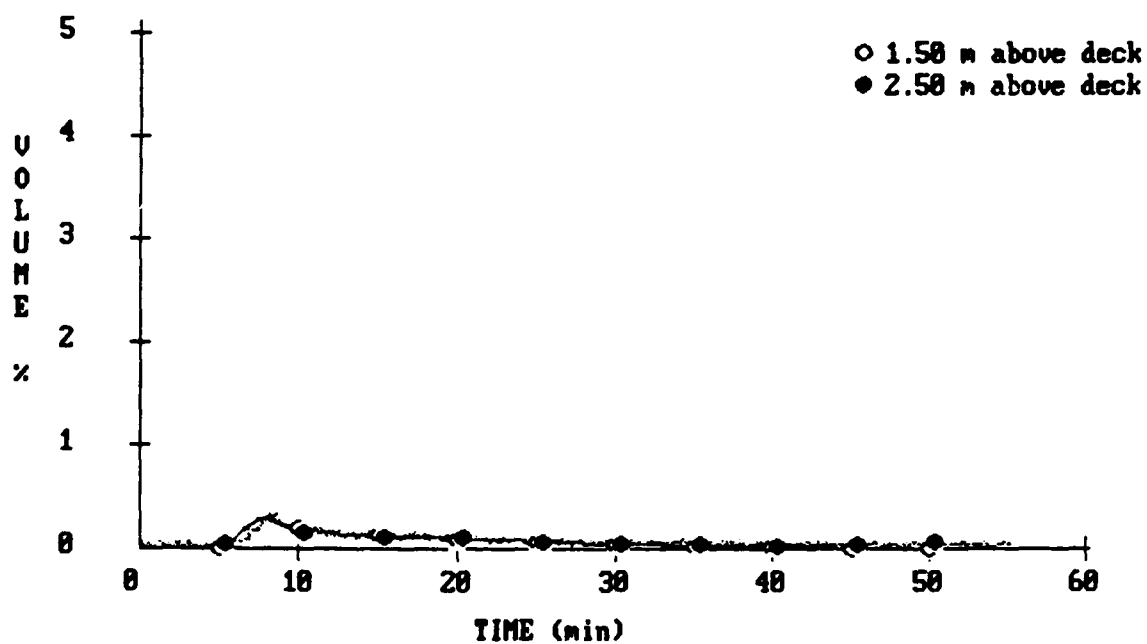


Fig. B-87- CO concentration in BERTHING 1 (3-76-2) during Test # 10

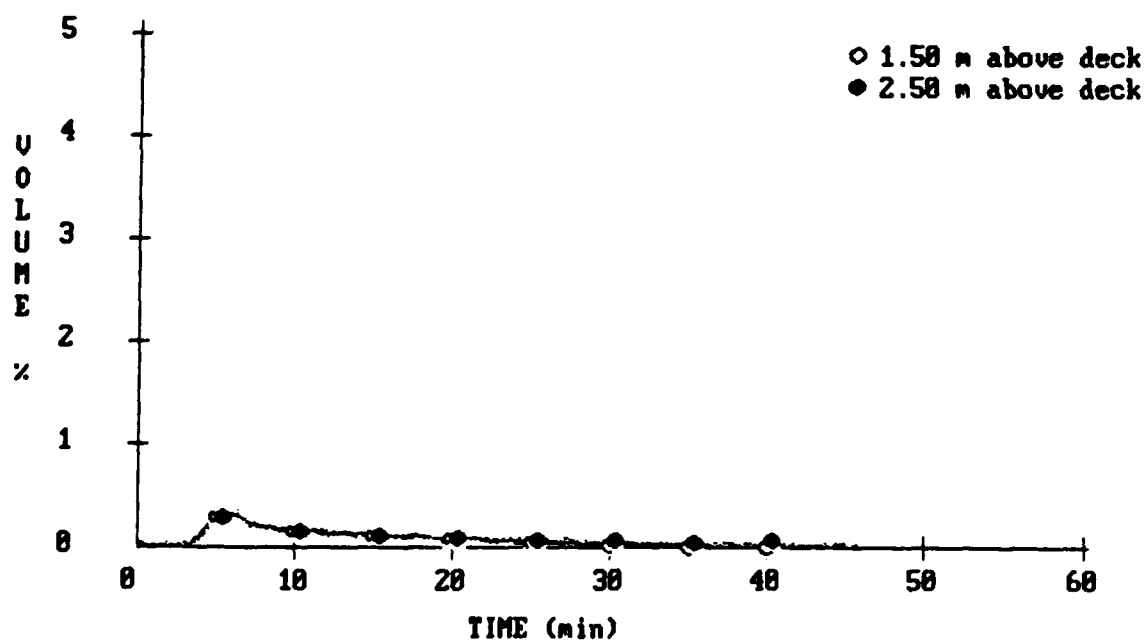


Fig. B-88- CO concentration in BERTHING 1 (3-76-2) during Test # 11



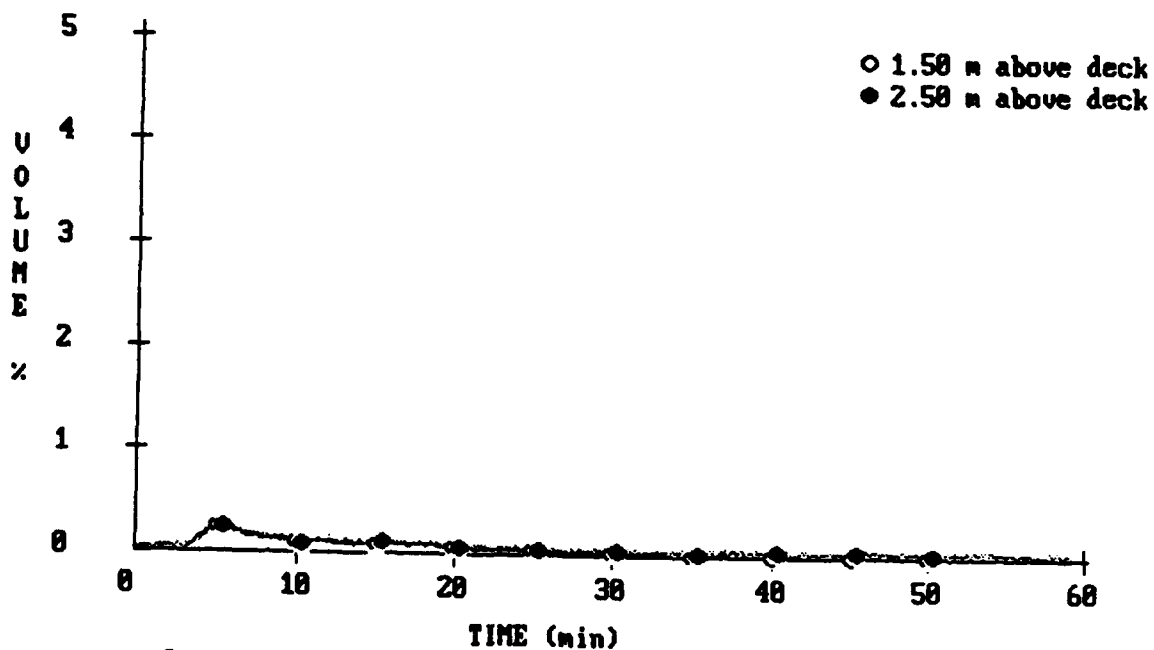


Fig. B-89- CO concentration in BERTHING 1 (3-76-2) during Test # 12

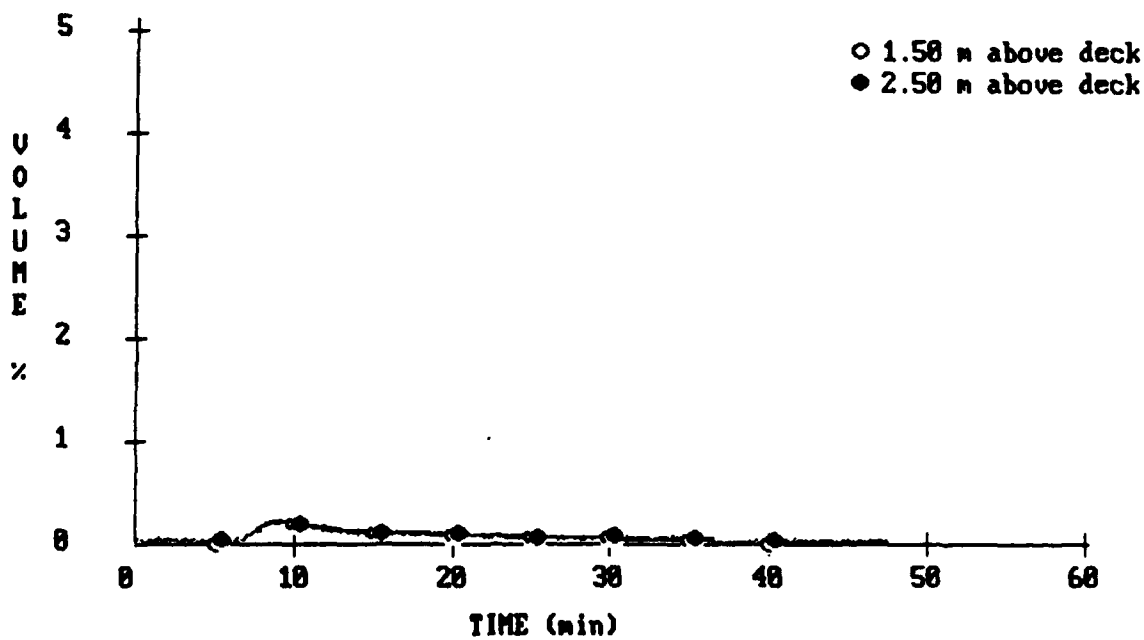


Fig. B-90- CO concentration in BERTHING 1 (3-76-2) during Test # 13

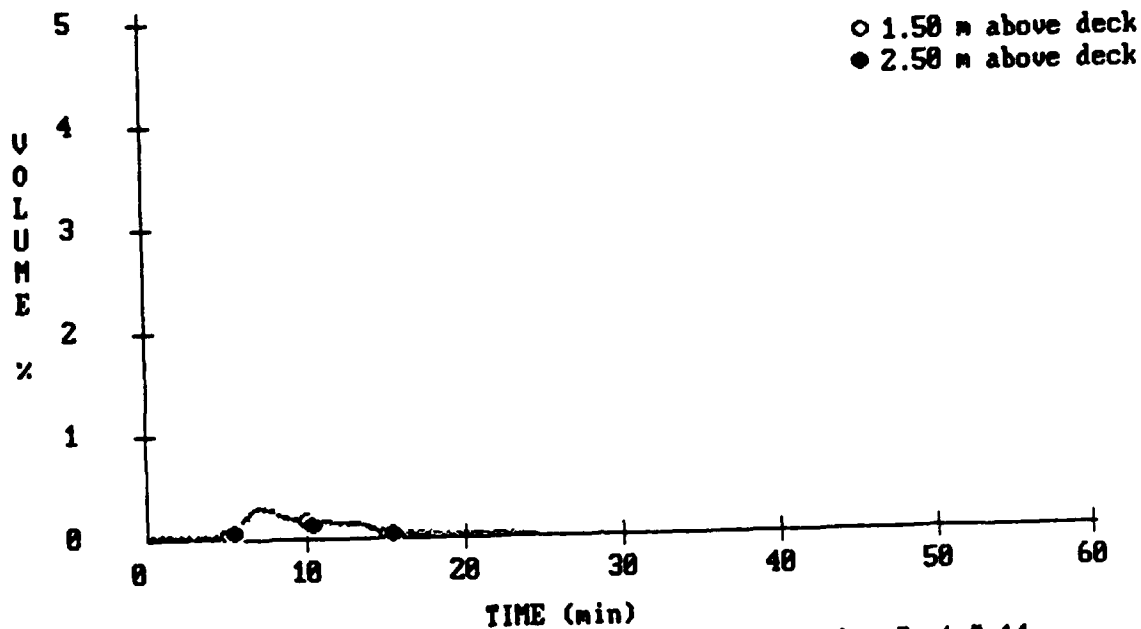


Fig. B-91- CO concentration in BERTHING 1 (3-76-2) during Test # 14

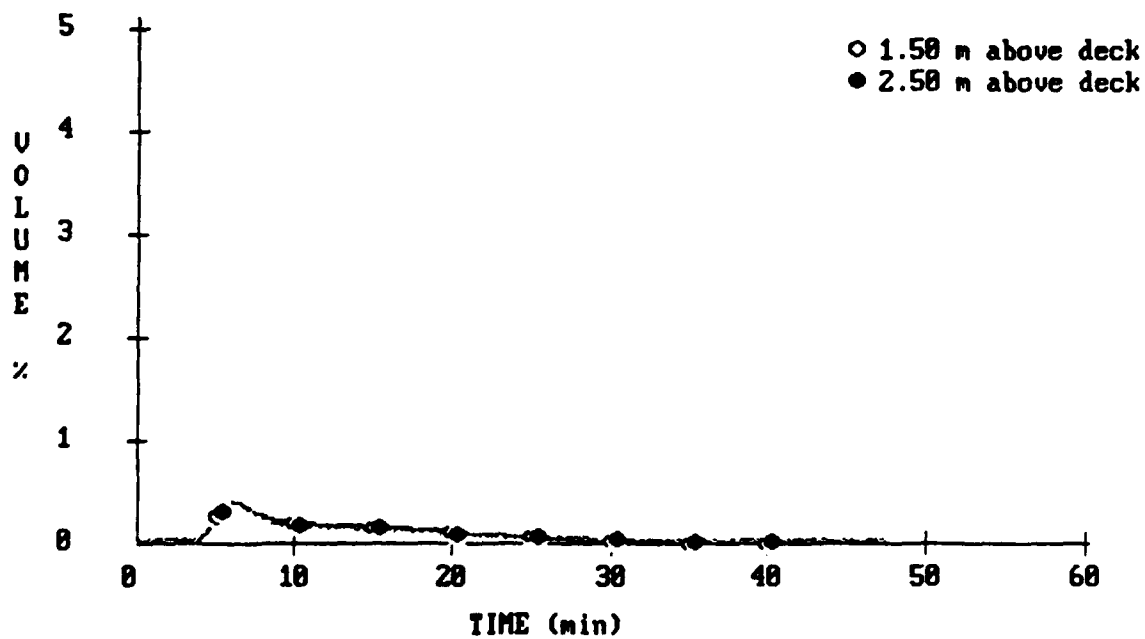


Fig. B-92- CO concentration in BERTHING 1 (3-76-2) during Test # 15

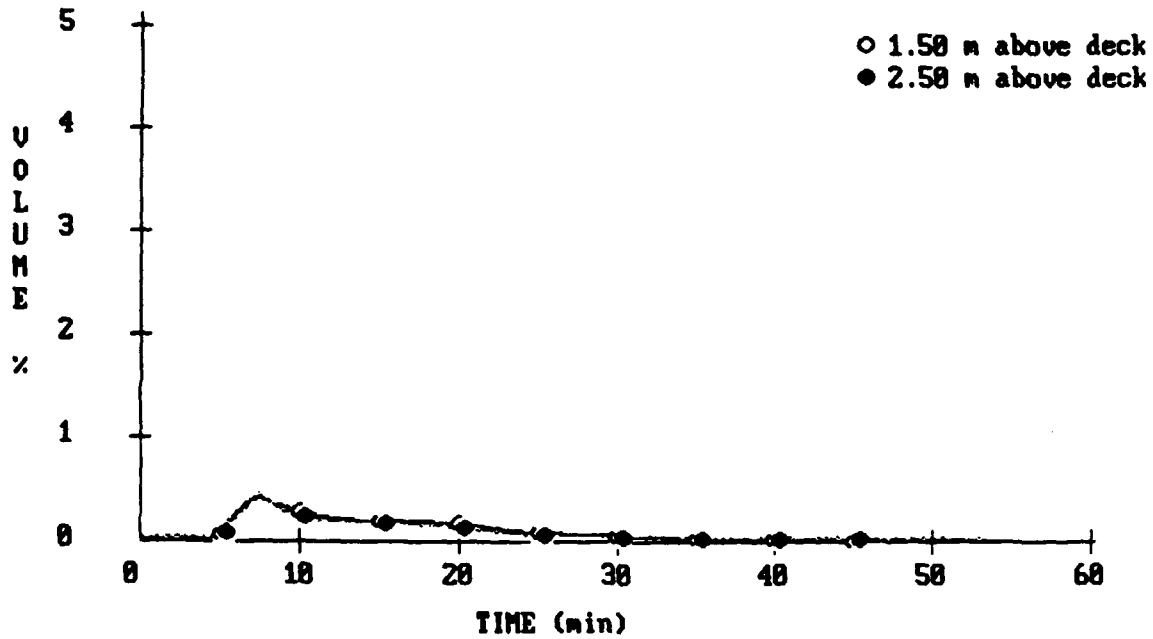


Fig. B-93- CO concentration in BERTHING 1 (3-76-2) during Test # 16

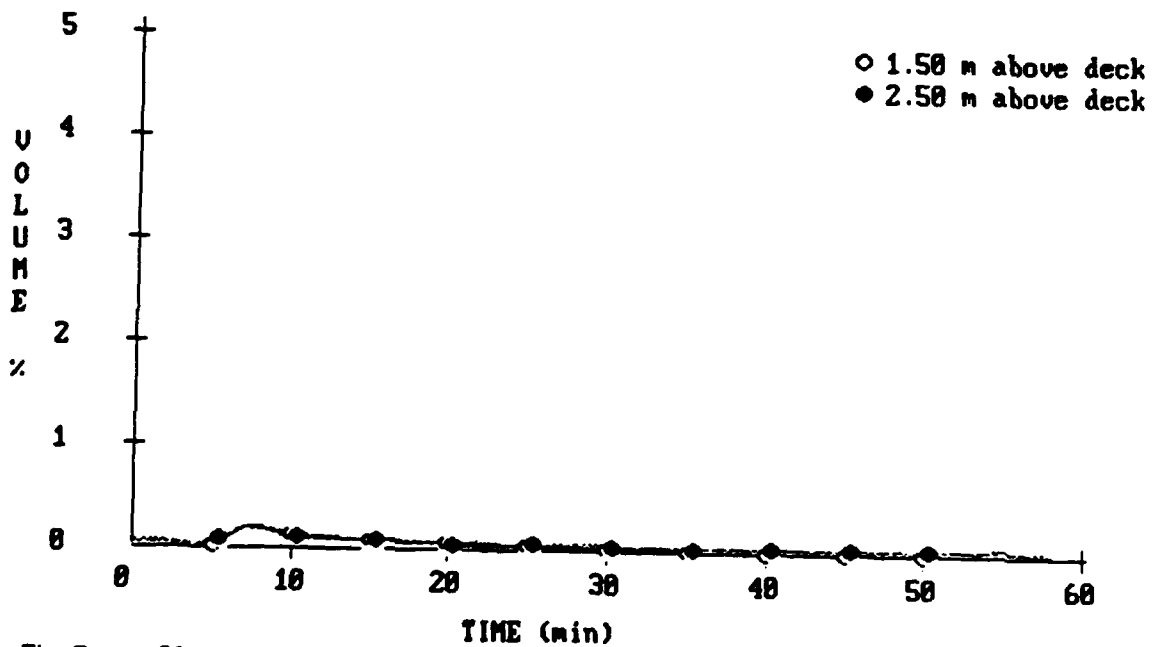


Fig. B-94- CO concentration in BERTHING 1 (3-76-2) during Test # 17

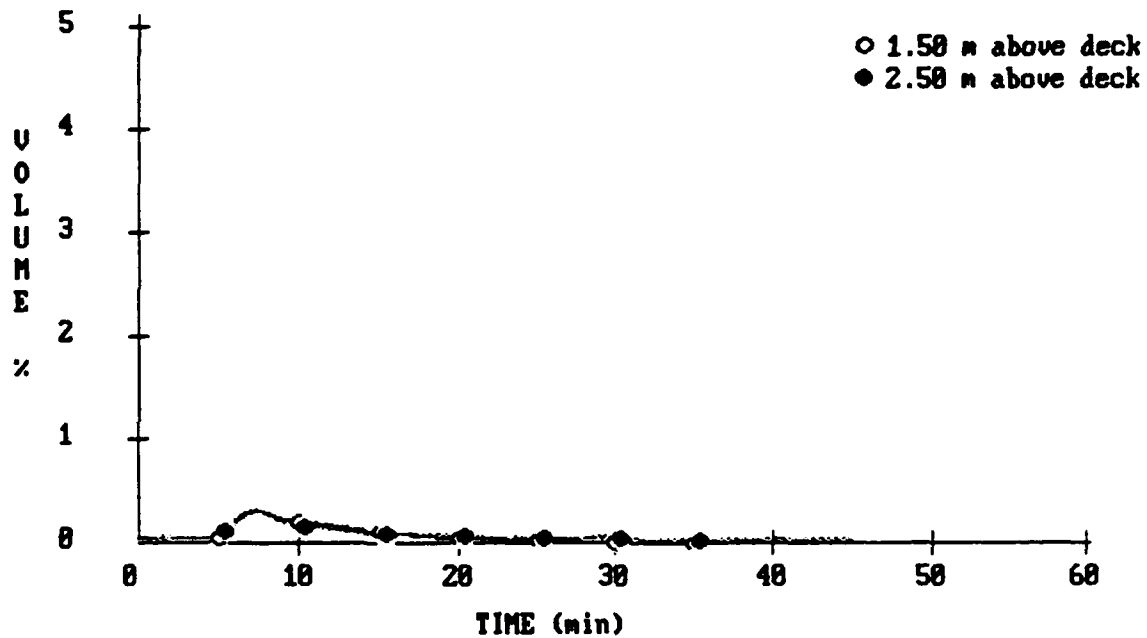


Fig. B-95- CO concentration in BERTHING 1 (3-76-2) during Test # 18

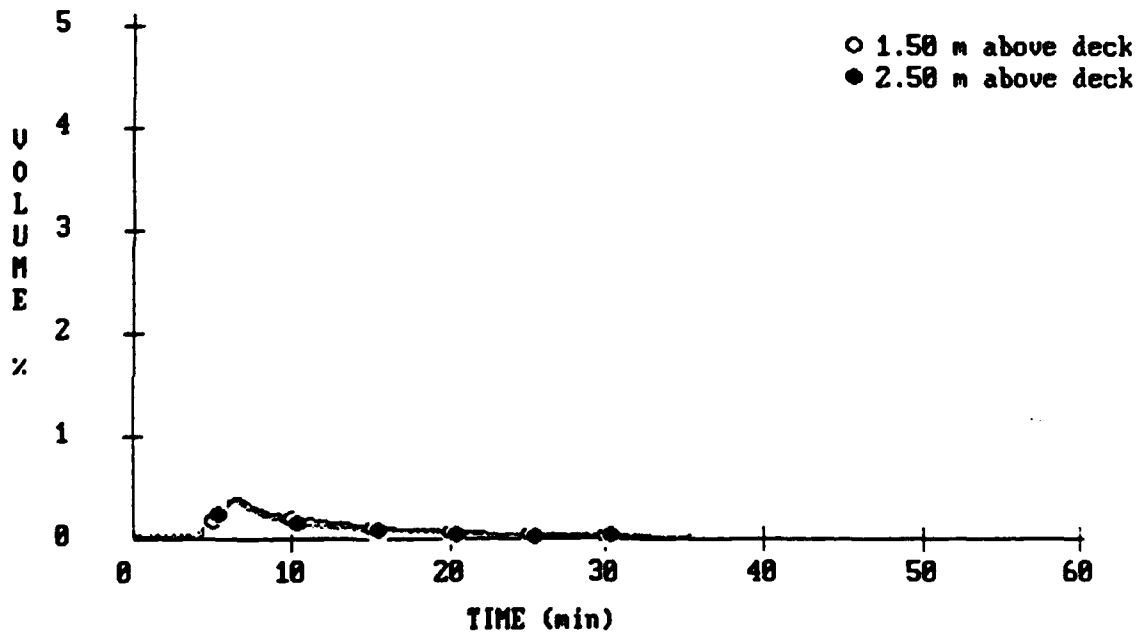


Fig. B-96- CO concentration in BERTHING 1 (3-76-2) during Test # 19

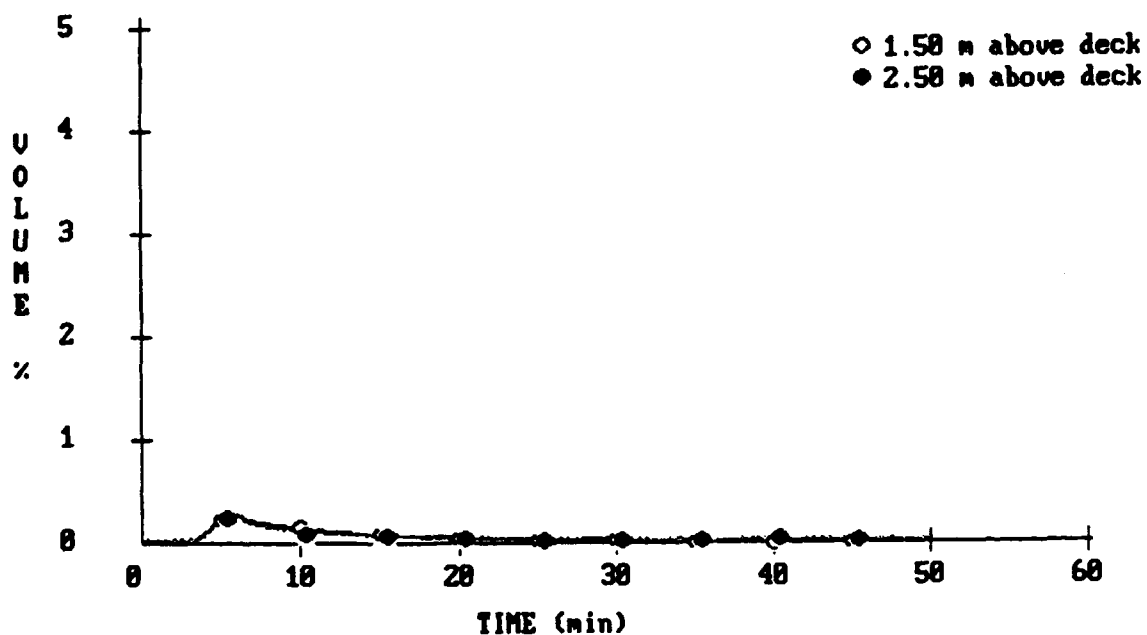


Fig. B-97- CO concentration in BERTHING 1 (3-76-2) during Test # 20

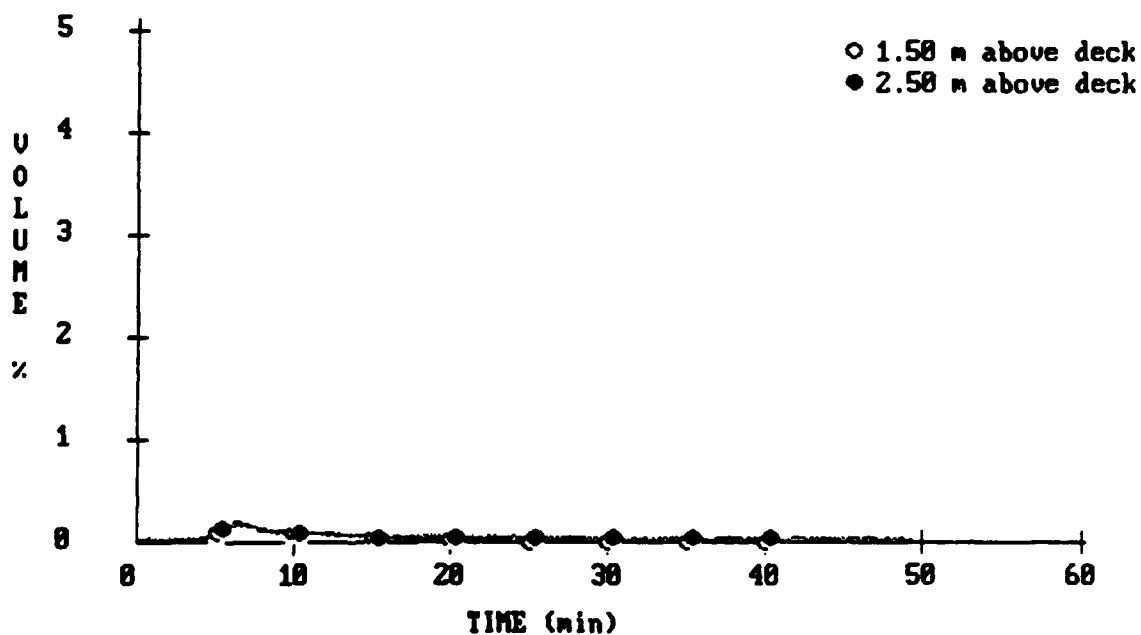


Fig. B-98- CO concentration in BERTHING 1 (3-76-2) during Test # 21

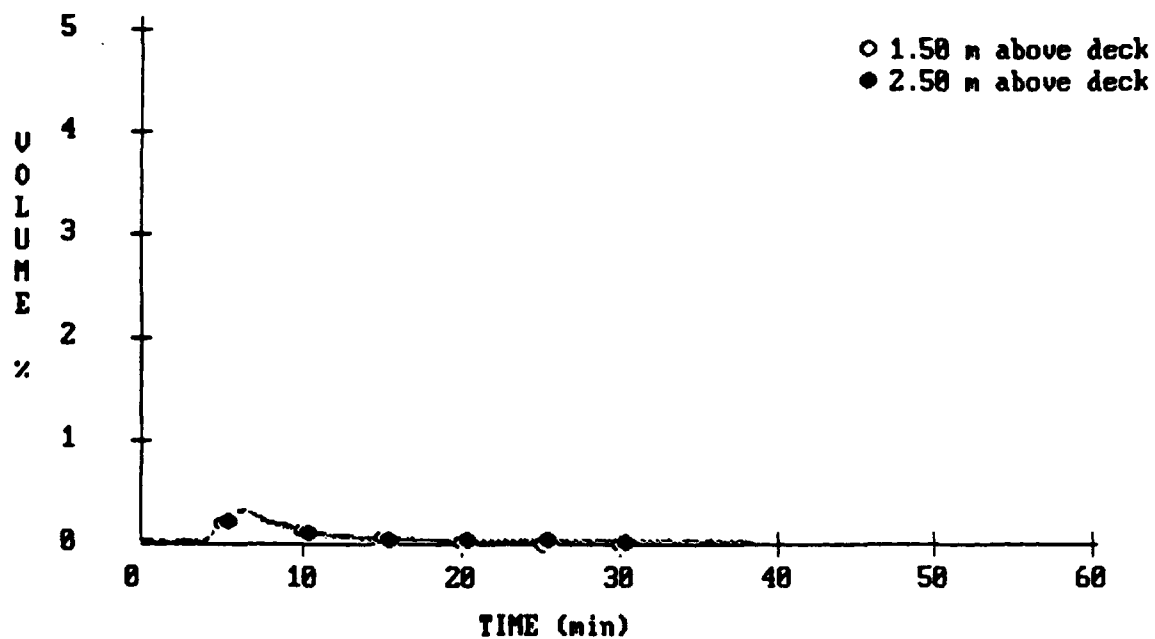


Fig. B-99- CO concentration in BERTHING 1 (3-76-2) during Test # 22

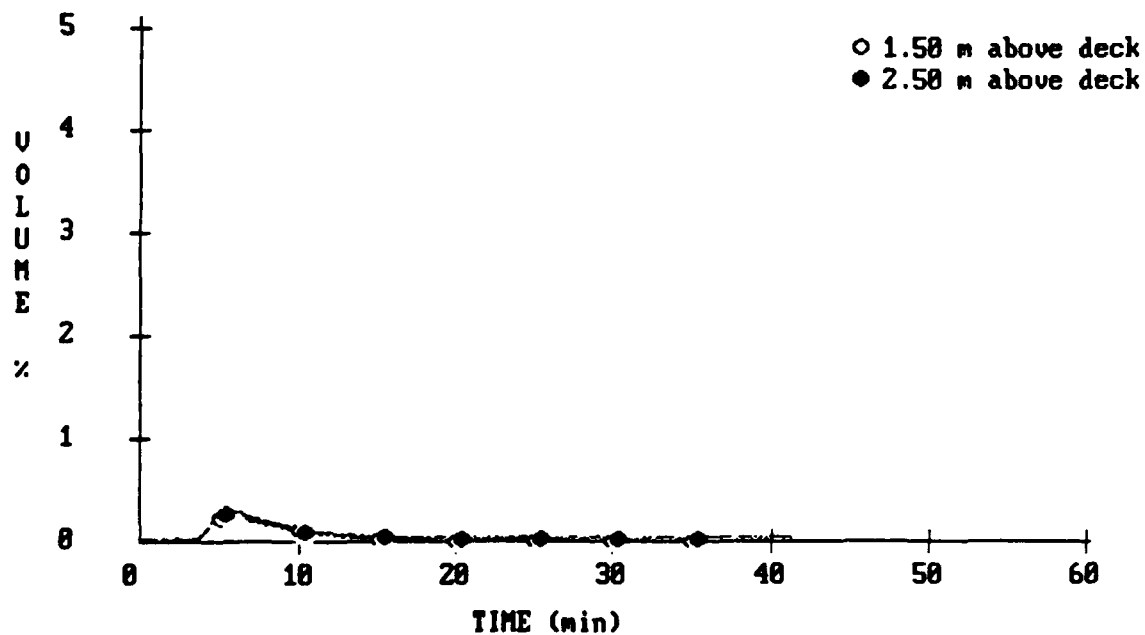


Fig. B-100- CO concentration in BERTHING 1 (3-76-2) during Test # 23

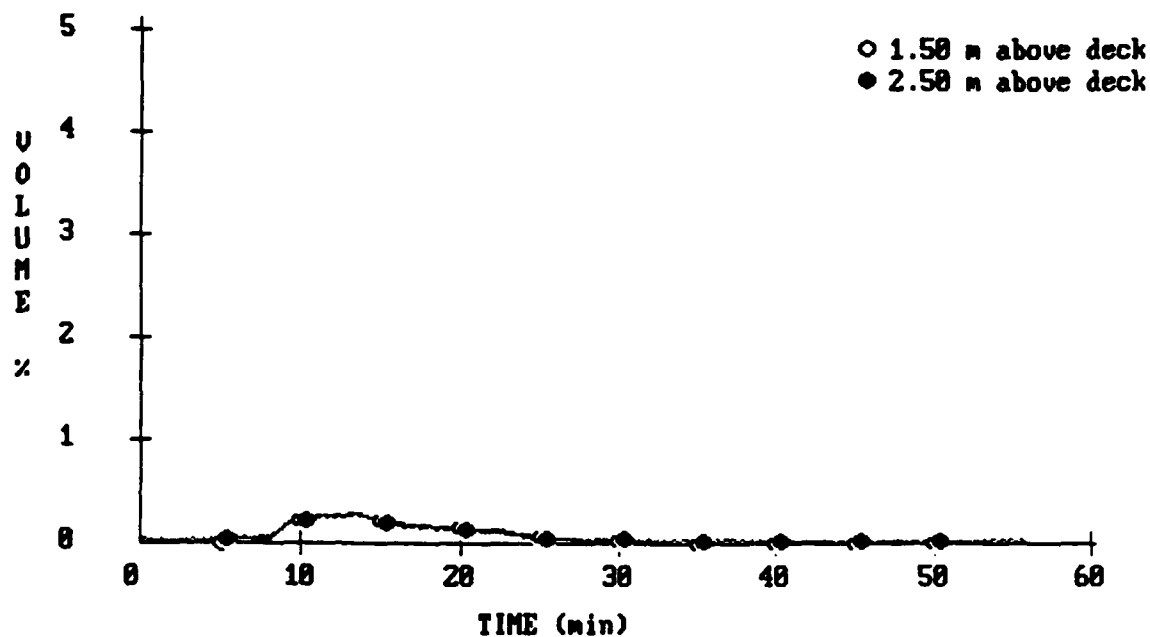


Fig. B-101- CO concentration in BERTHING 1 (3-76-2) during Test # 21

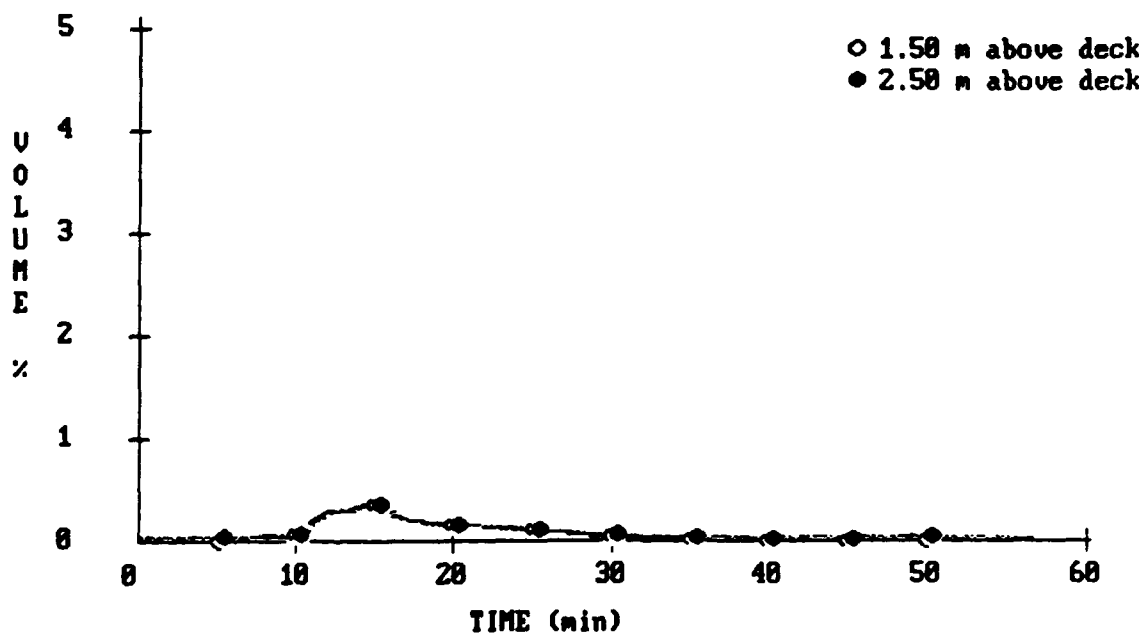


Fig. B-102- CO concentration in BERTHING 1 (3-76-2) during Test # 25

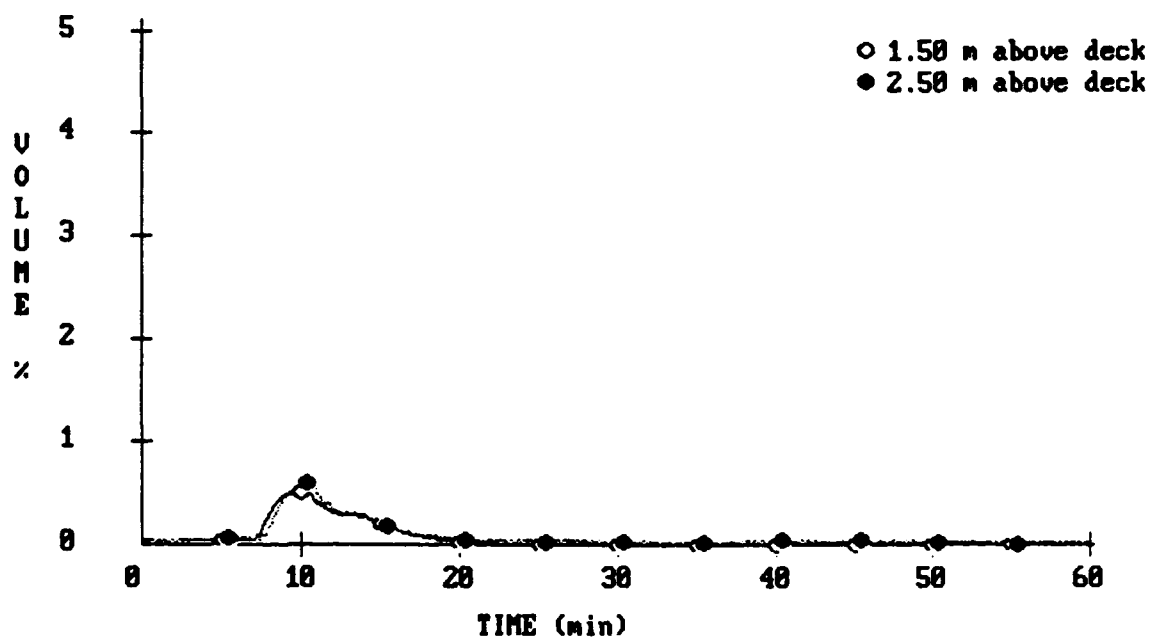


Fig. B-103- CO concentration in BERTHING 1 (3-76-2) during Test # 26

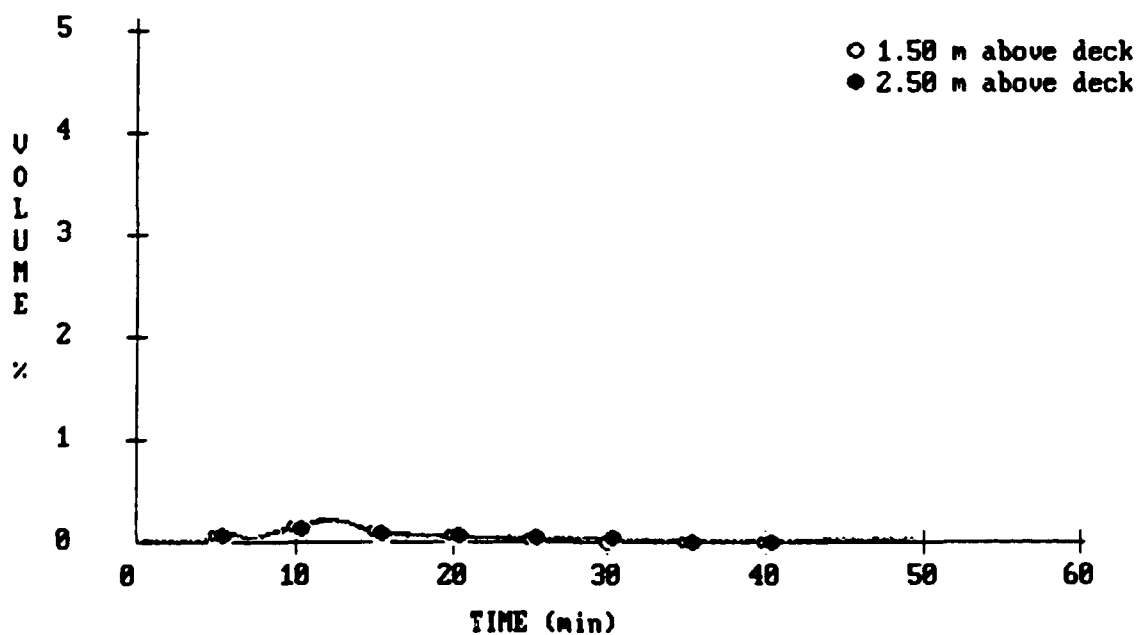


Fig. B-104- CO concentration in BERTHING 1 (3-76-2) during Test # 27



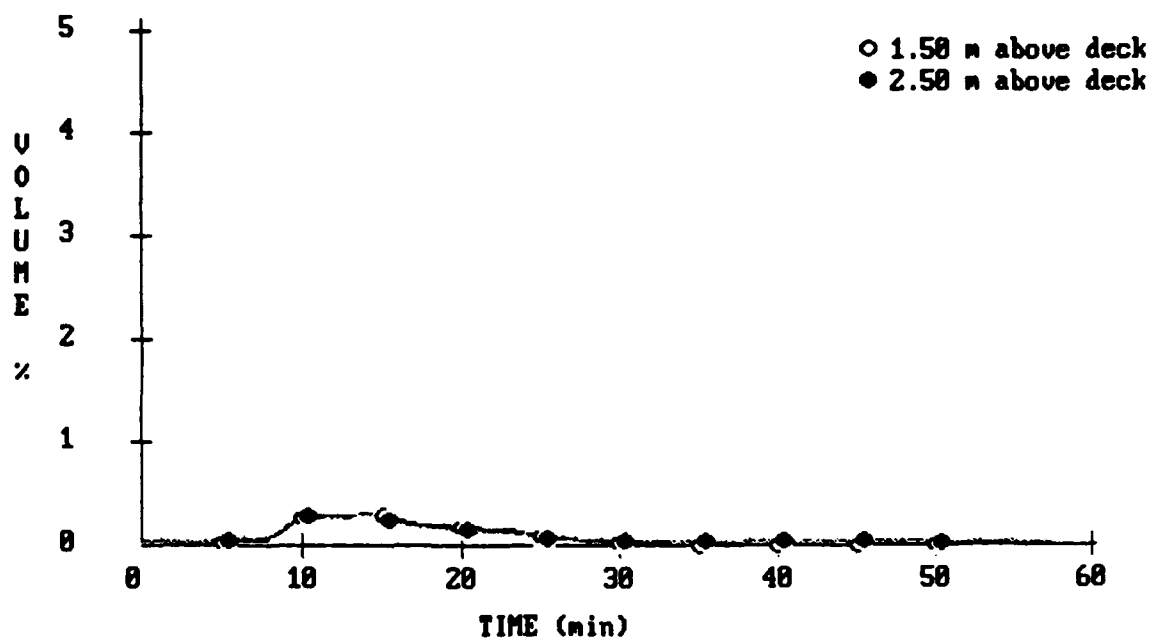


Fig. B-105- CO concentration in BERTHING 1 (3-76-2) during Test # 28

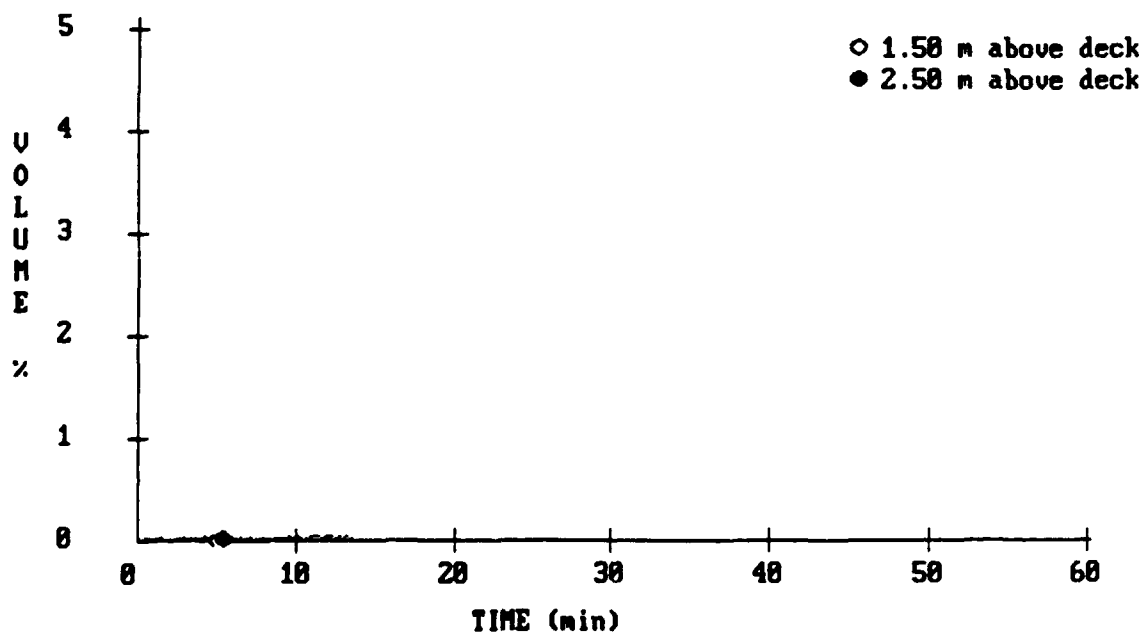


Fig. B-106- CO concentration in BERTHING 1 (3-76-2) during Test # 29

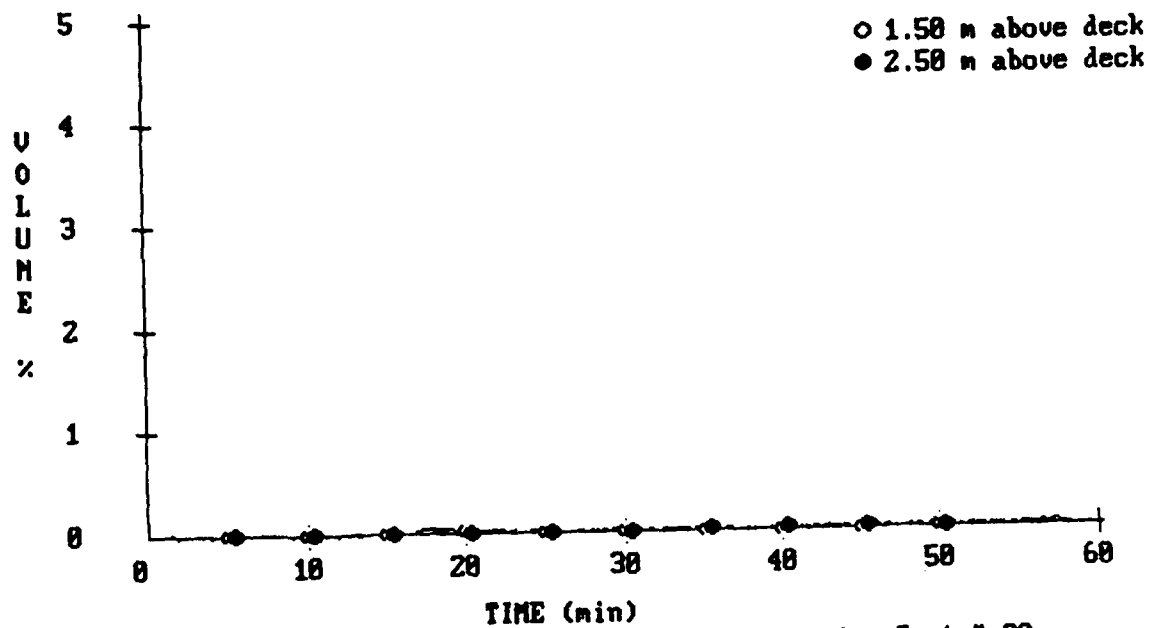


Fig. B-107- CO concentration in BERTHING 1 (3-76-2) during Test # 30

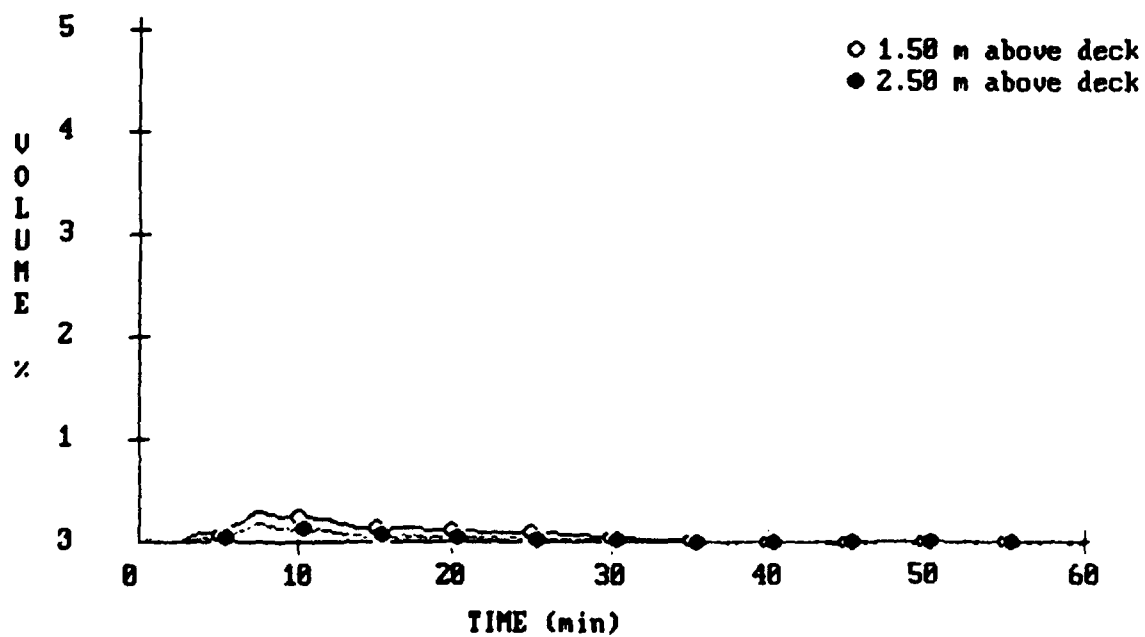


Fig. B-108- CO concentration in BERTHING 1 (3-76-2) during Test # 31

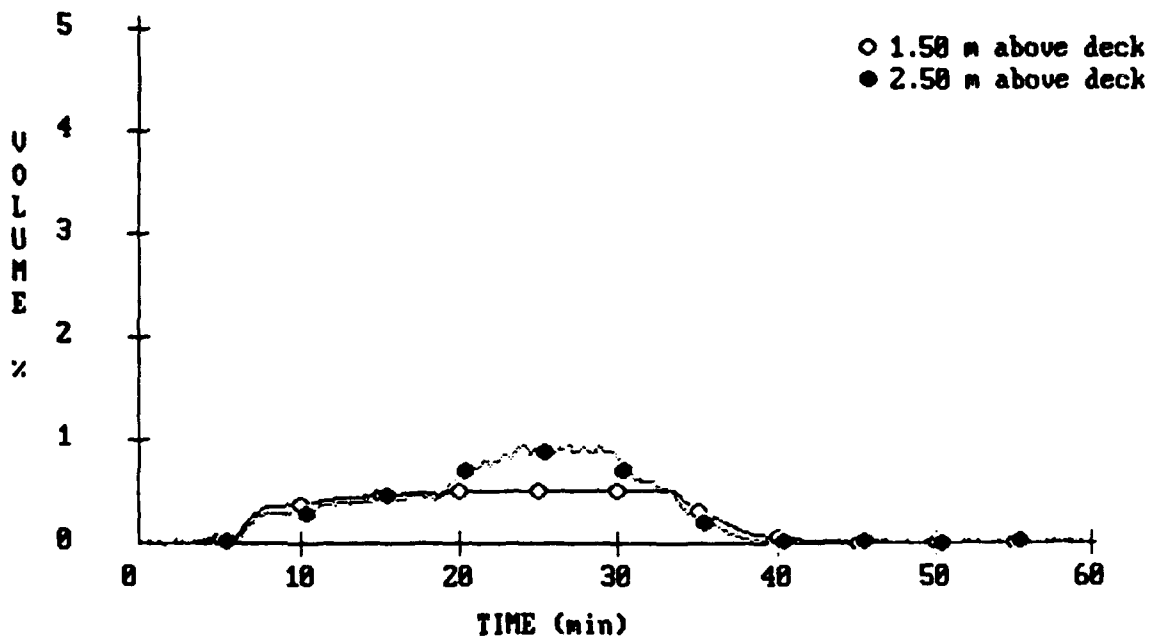


Fig. B-109- CO concentration in BERTHING 1 (3-76-2) during Test # 32

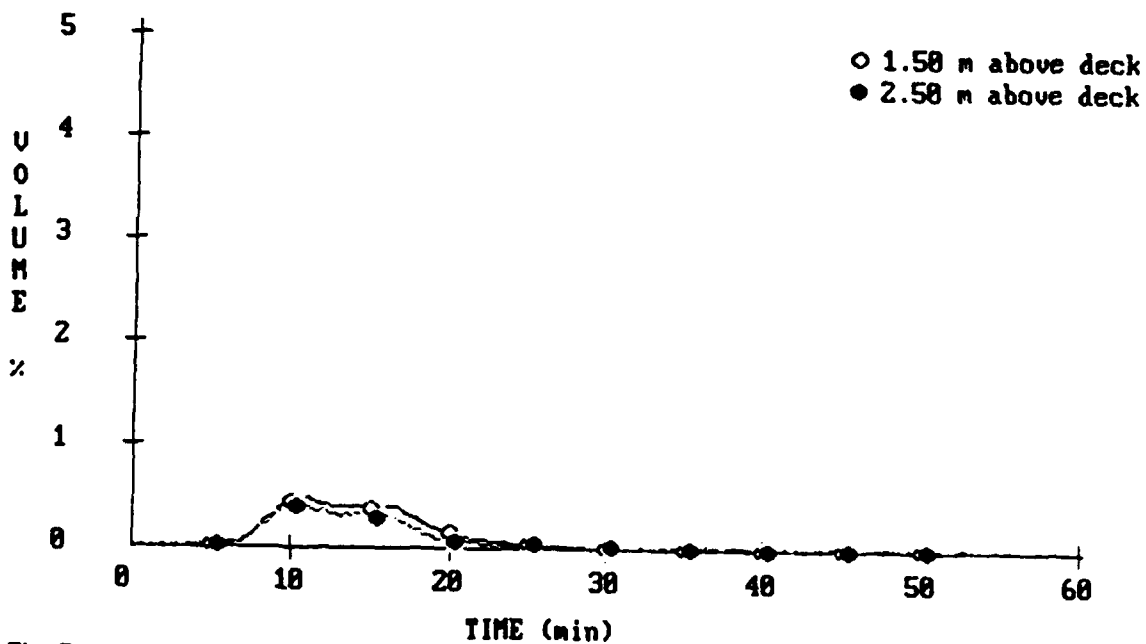


Fig. B-110- CO concentration in BERTHING 1 (3-76-2) during Test # 33

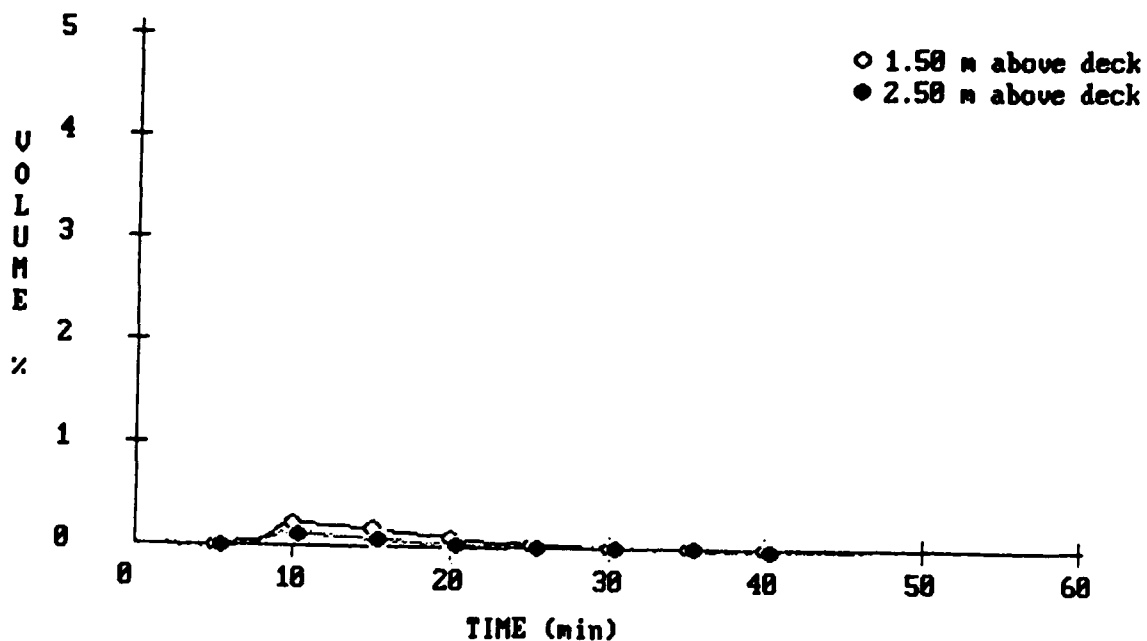


Fig. B-111- CO concentration in BERTHING 1 (3-76-2) during Test # 34

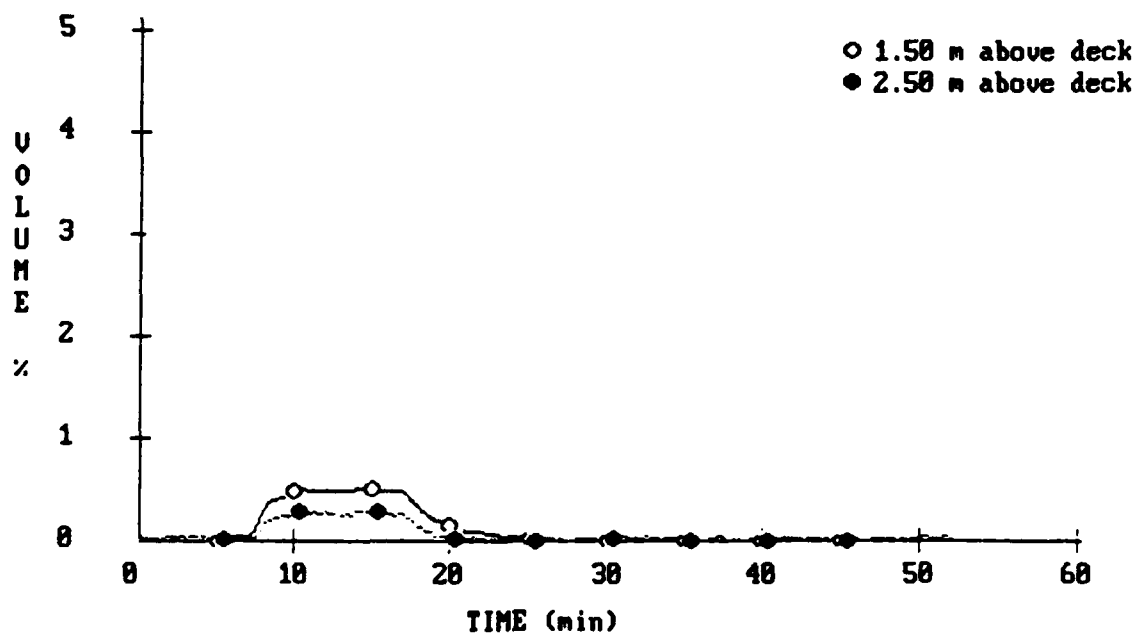


Fig. B-112- CO concentration in BERTHING 1 (3-76-2) during Test # 35

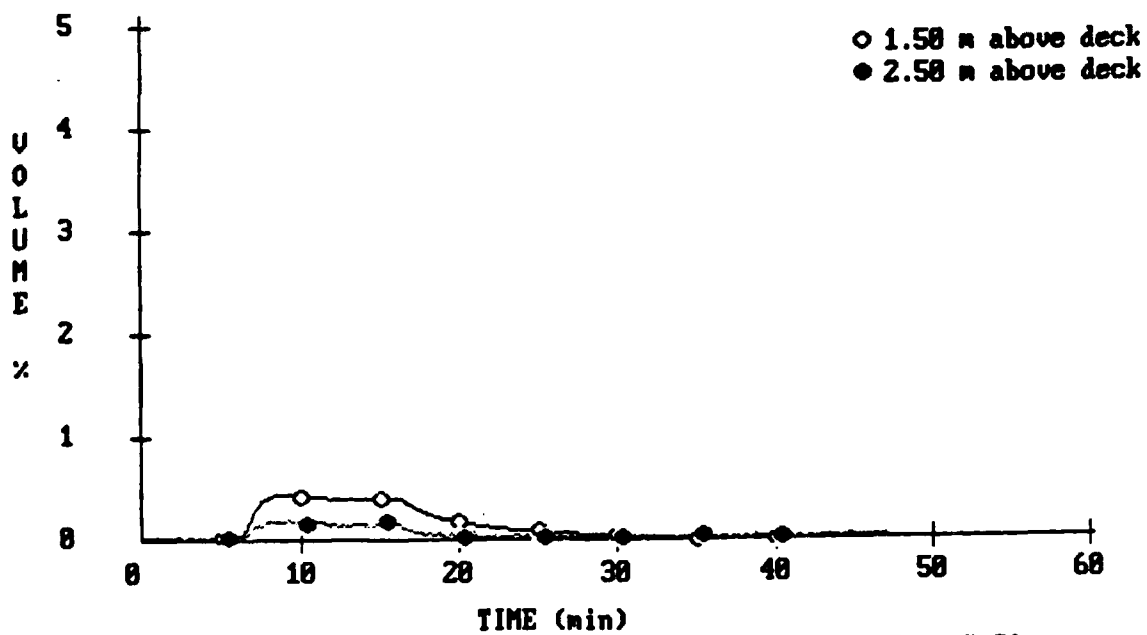


Fig. B-113- CO concentration in BERTHING 1 (3-76-2) during Test # 36

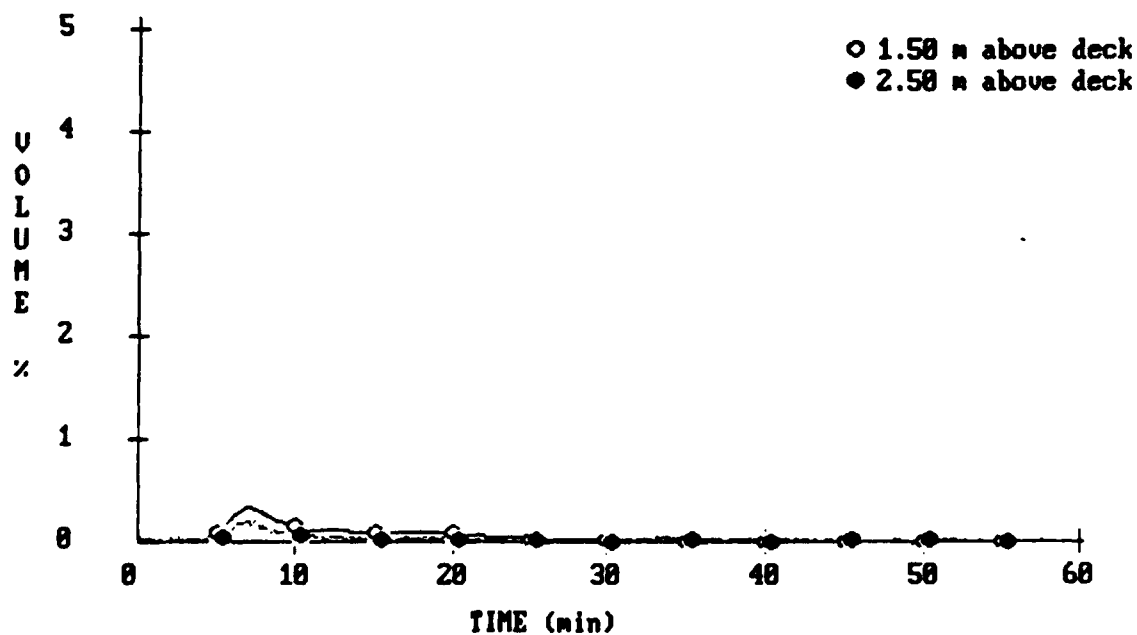


Fig. B-114- CO concentration in BERTHING 1 (3-76-2) during Test # 37

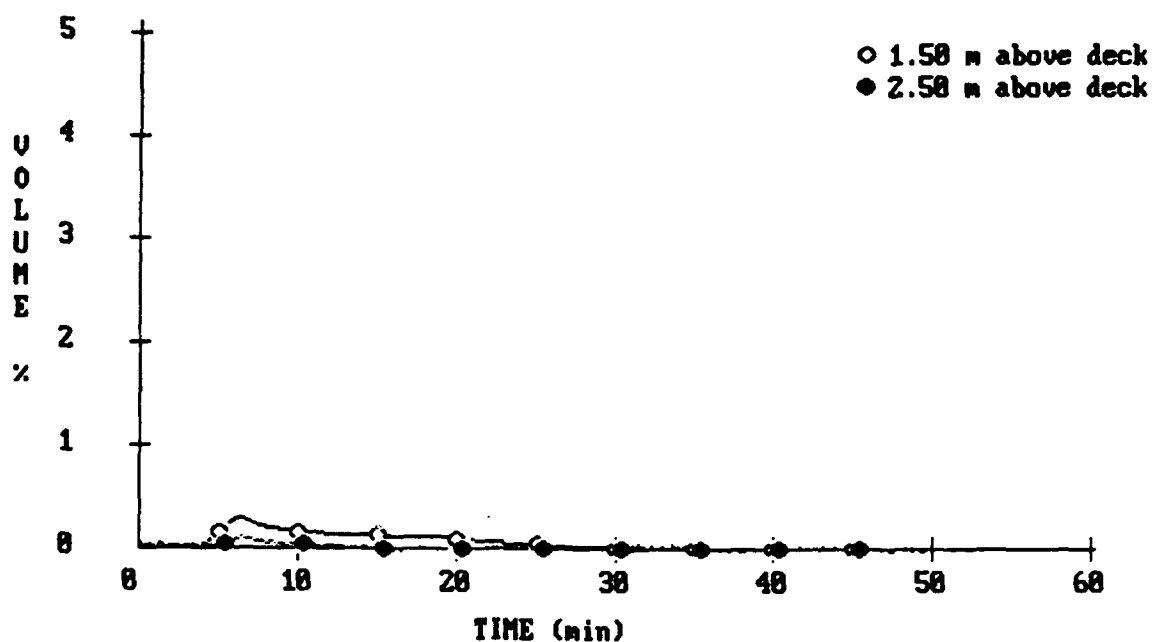


Fig. B-115- CO concentration in BERTHING 1 (3-76-2) during Test # 38

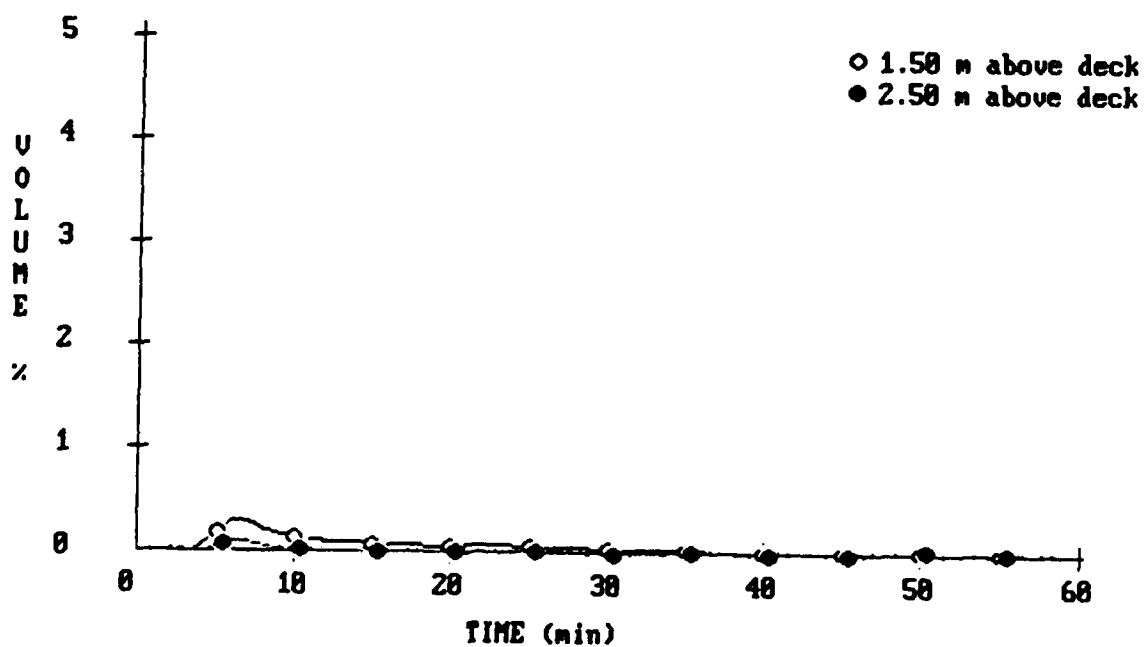


Fig. B-116- CO concentration in BERTHING 1 (3-76-2) during Test # 39

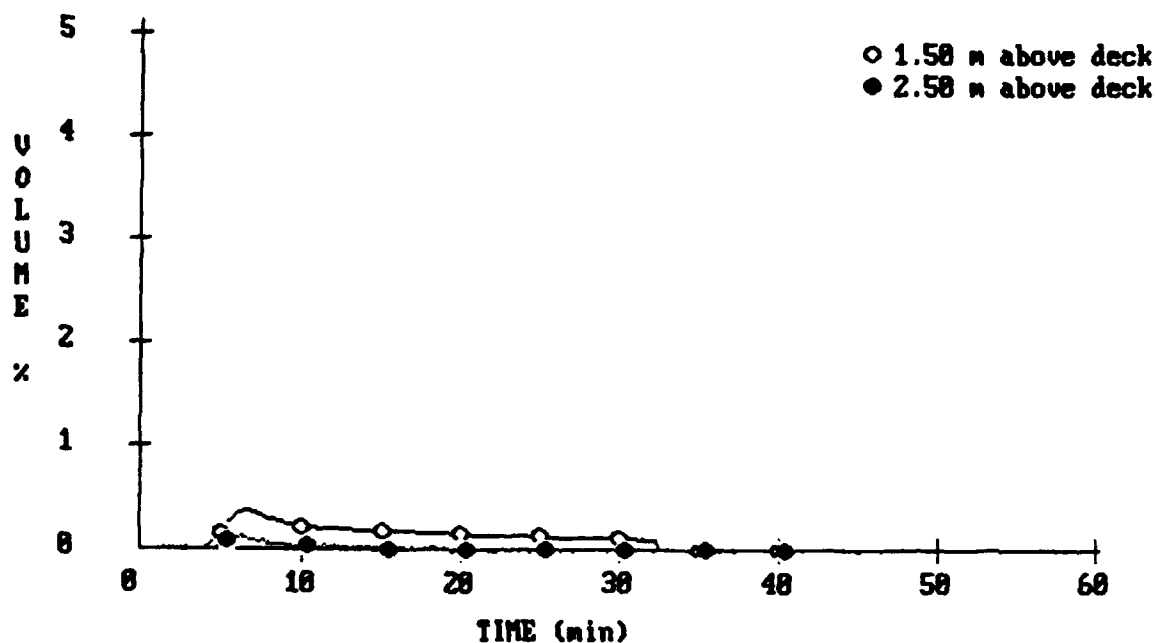


Fig. B-117- CO concentration in BERTHING 1 (3-76-2) during Test # 40

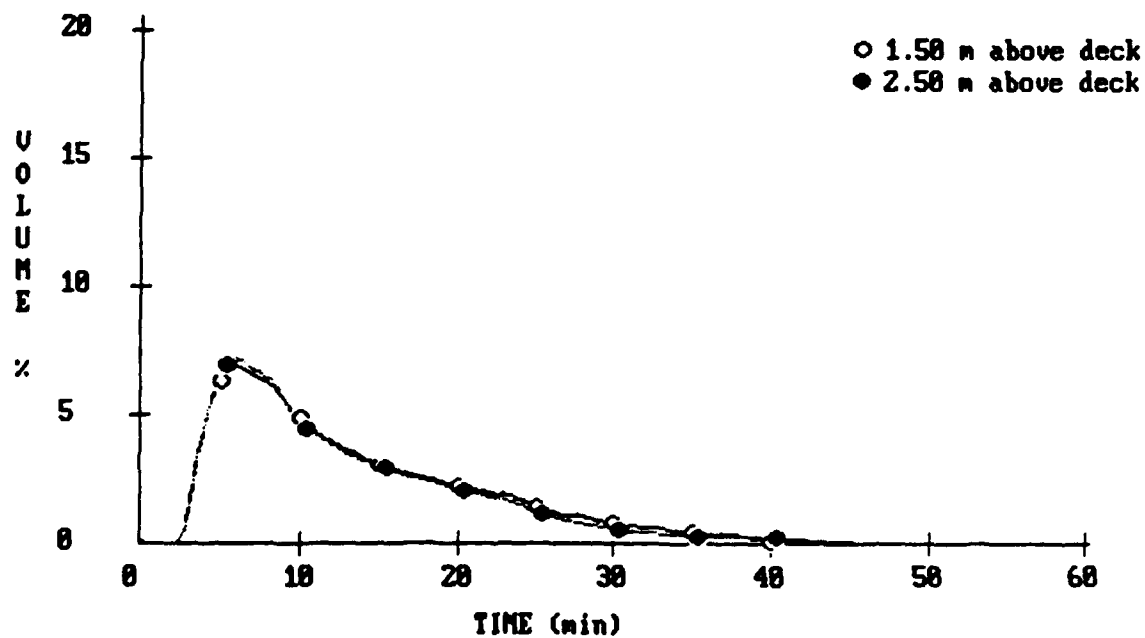


Fig. B-118- CO2 concentration in BERTHING 1 (3-76-2) during Test # 2

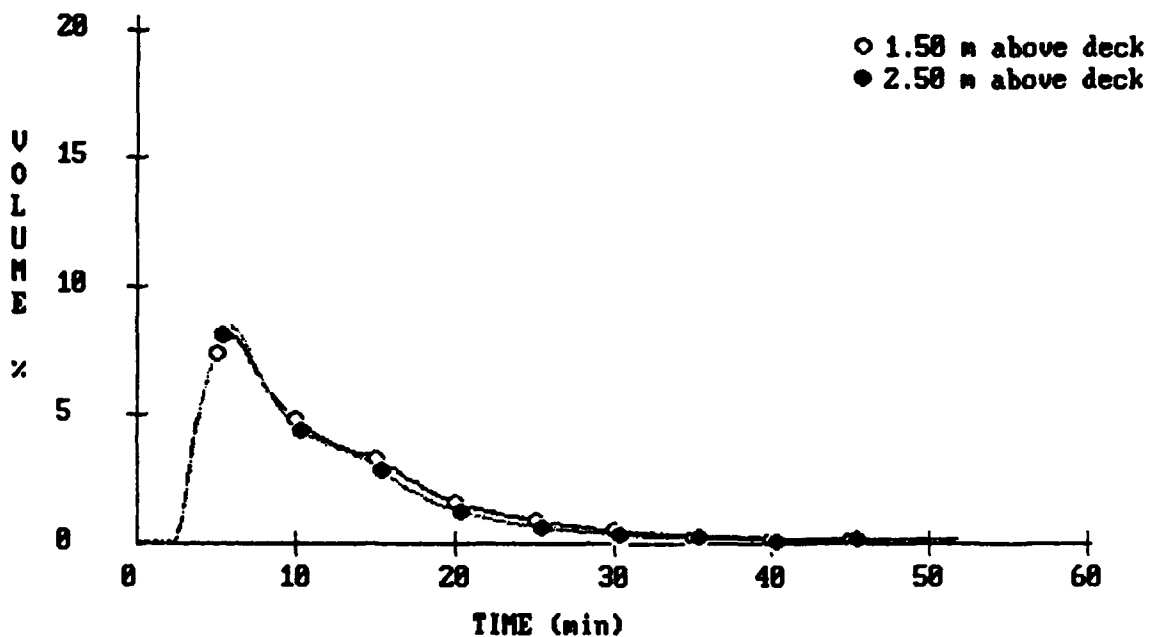


Fig. B-119- CO2 concentration in BERTHING 1 (3-76-2) during Test # 3

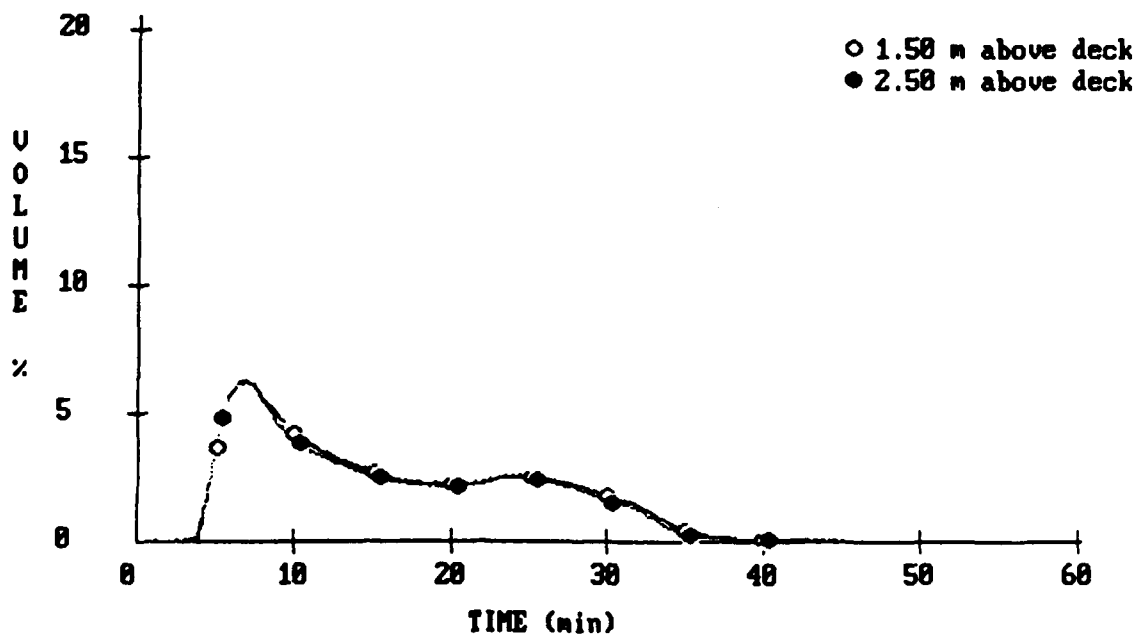


Fig. B-120- CO2 concentration in BERTHING 1 (3-76-2) during Test # 4



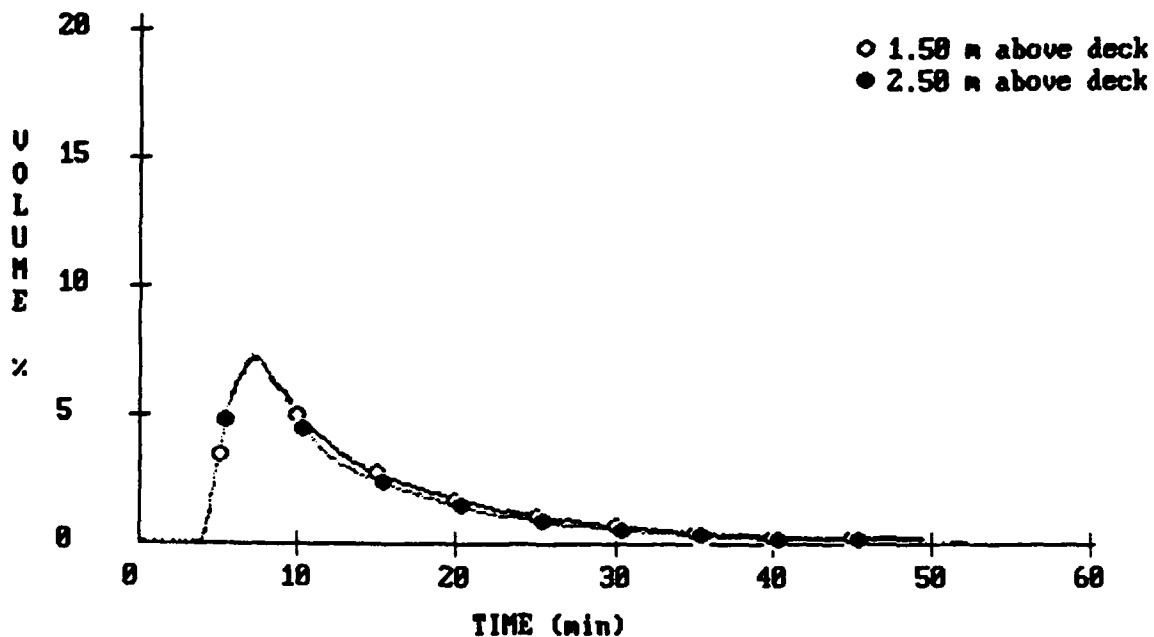


Fig. B-121- CO2 concentration in BERTHING 1 (3-76-2) during Test # 5

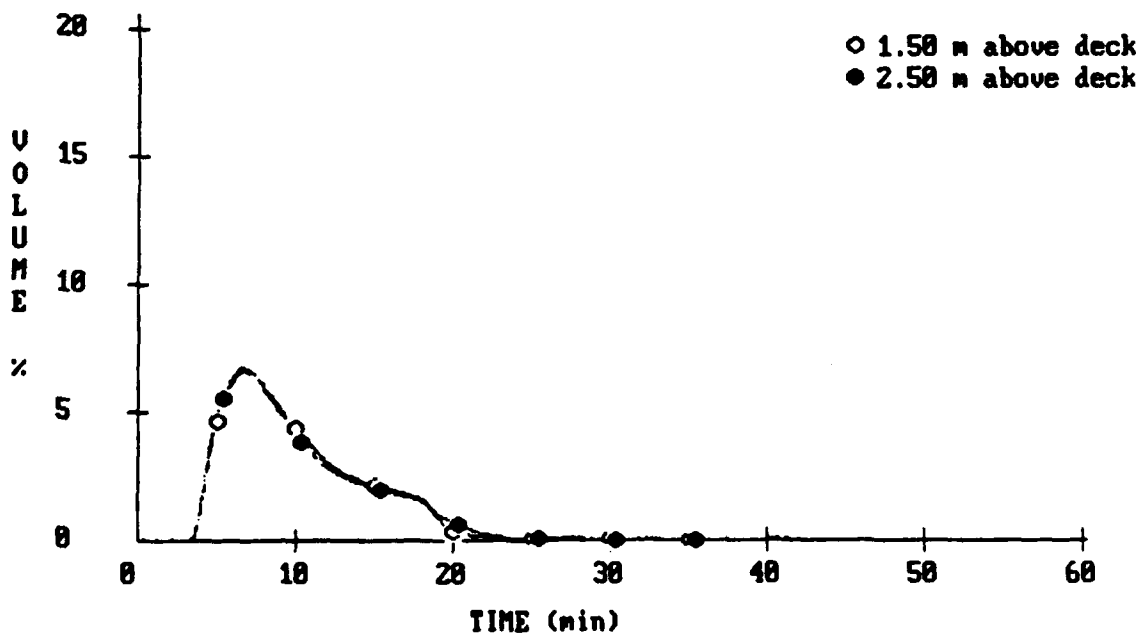


Fig. B-122- CO2 concentration in BERTHING 1 (3-76-2) during Test # 6

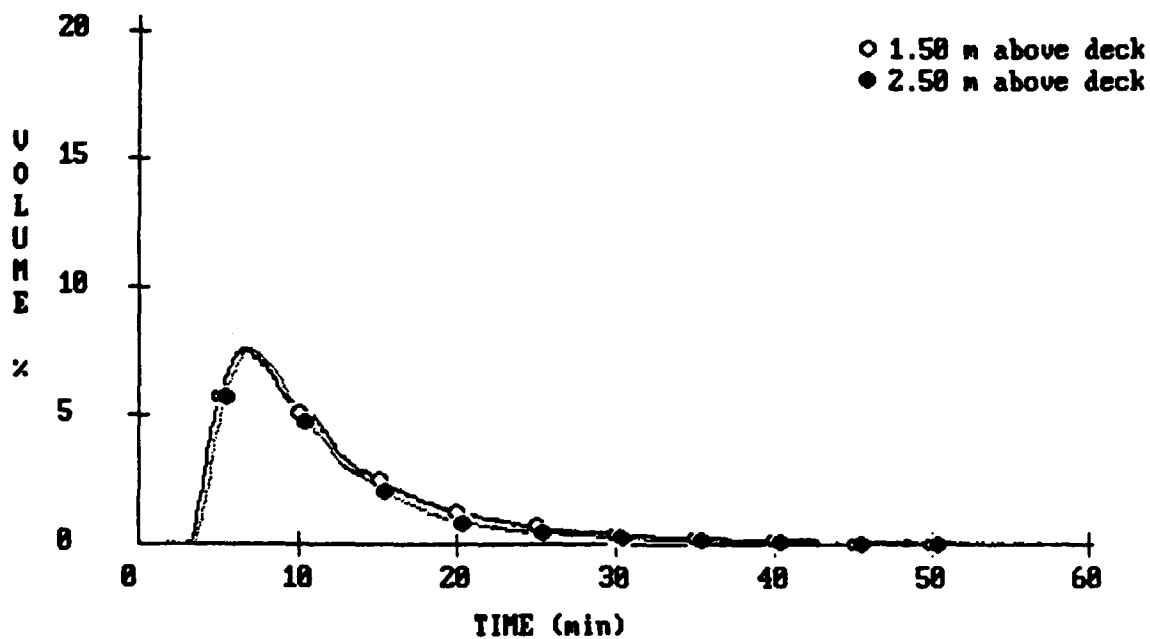


Fig. B-123- CO2 concentration in BERTHING 1 (3-76-2) during Test # 7

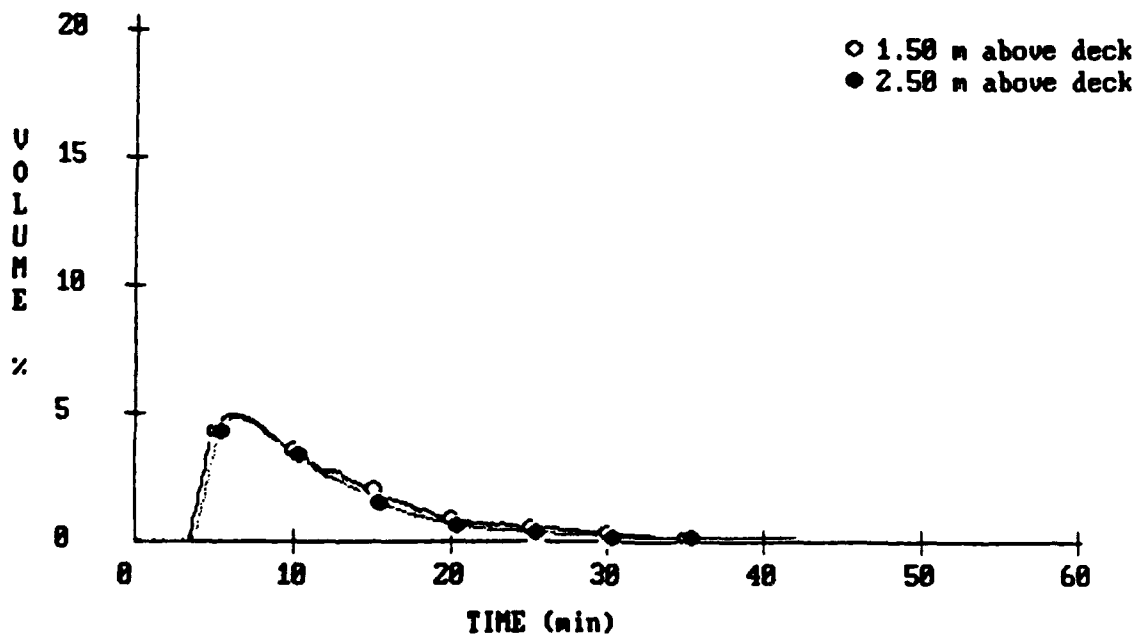


Fig. B-124- CO2 concentration in BERTHING 1 (3-76-2) during Test # 8

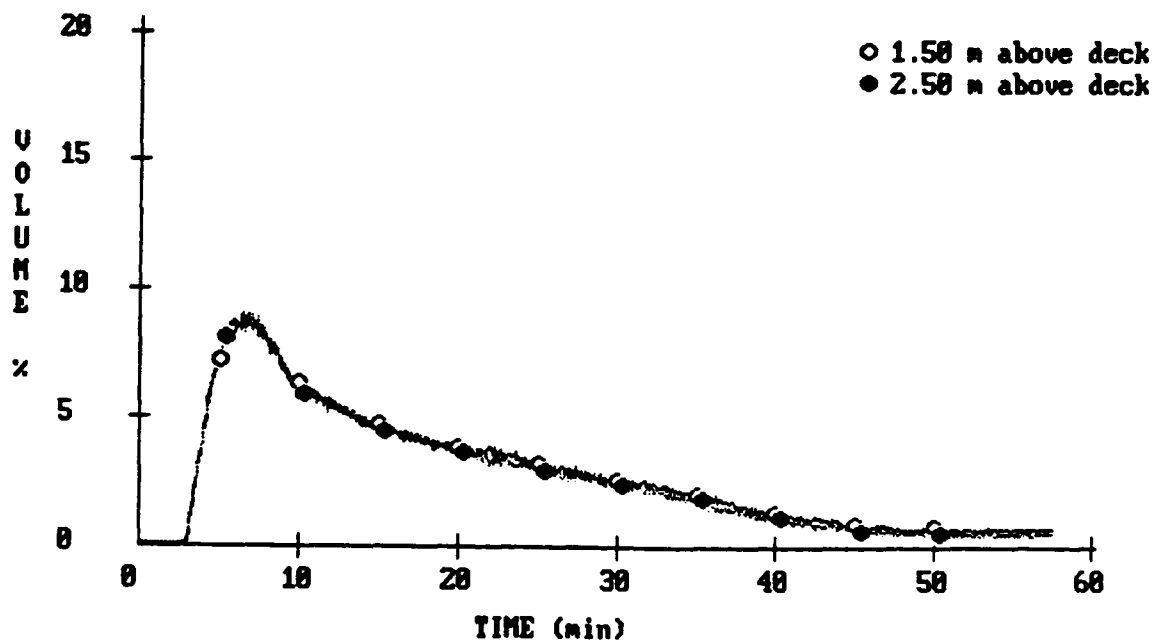


Fig. B-125- CO2 concentration in BERTHING 1 (3-76-2) during Test # 9

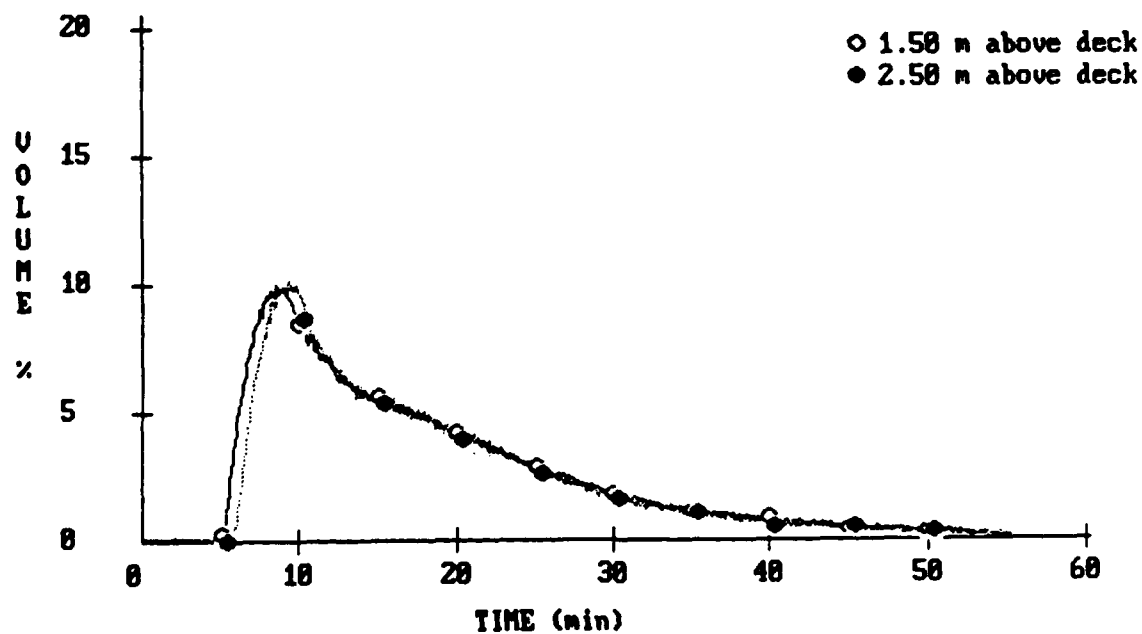


Fig. B-126- CO2 concentration in BERTHING 1 (3-76-2) during Test # 10

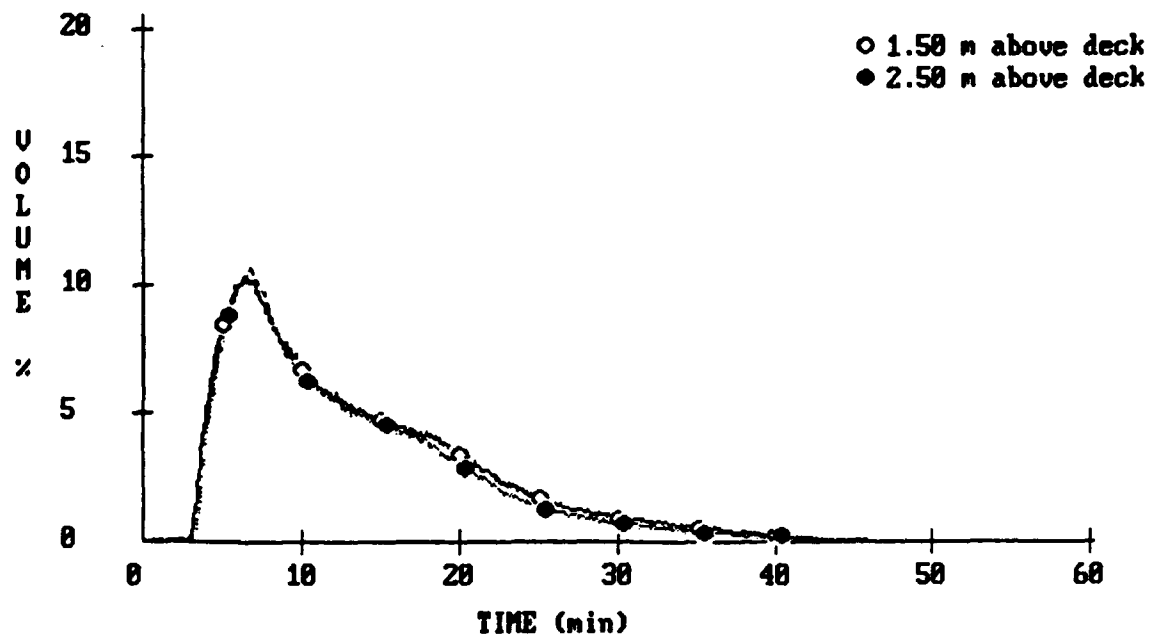


Fig. B-127- CO2 concentration in BERTHING 1 (3-76-2) during Test # 11

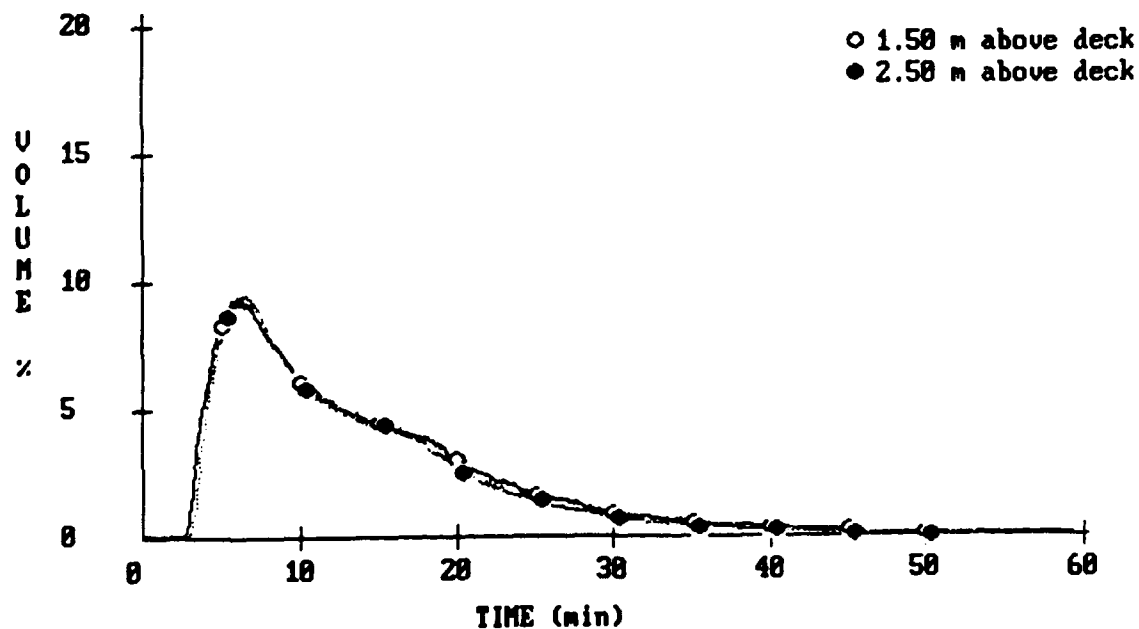


Fig. B-128- CO2 concentration in BERTHING 1 (3-76-2) during Test # 12

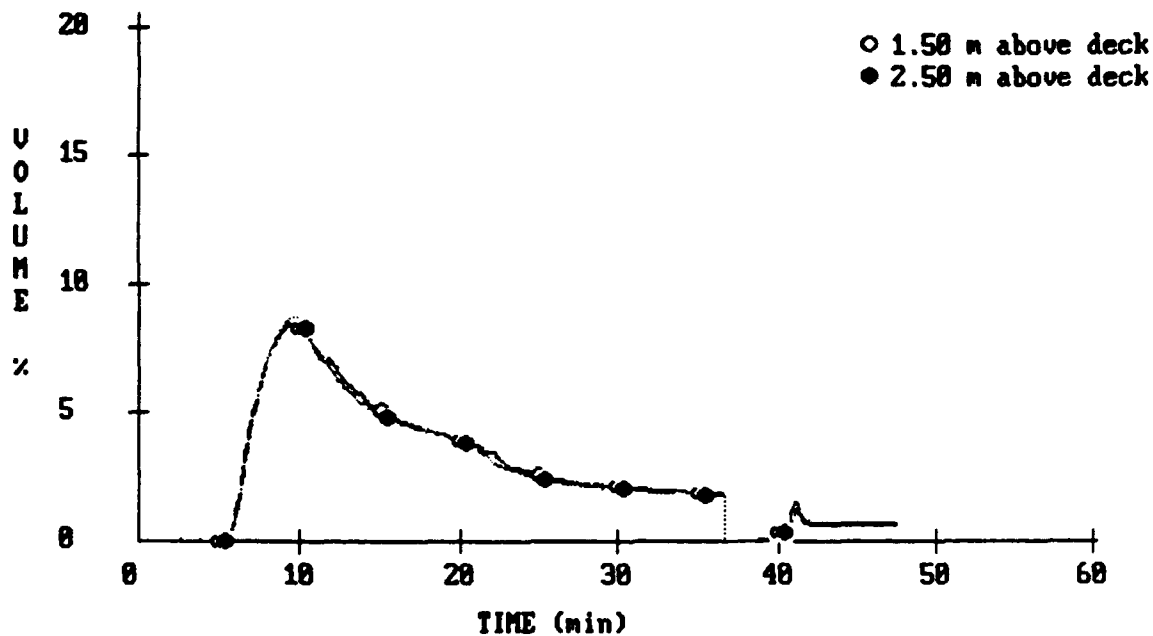


Fig. B-129- CO2 concentration in BERTHING 1 (3-76-2) during Test # 13

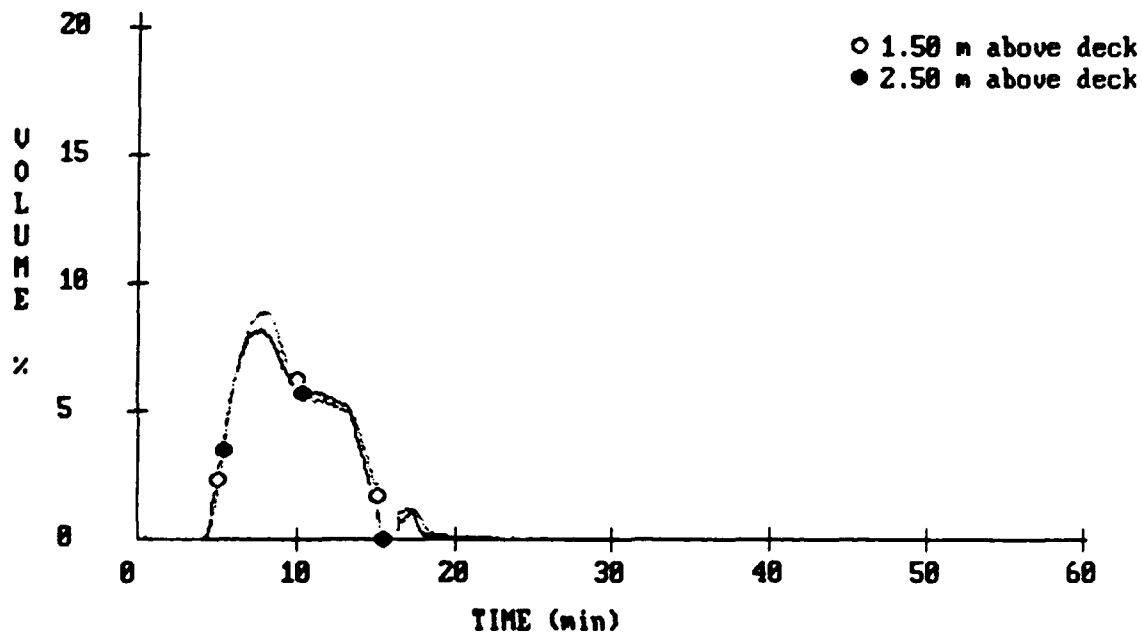


Fig. B-130- CO2 concentration in BERTHING 1 (3-76-2) during Test # 14

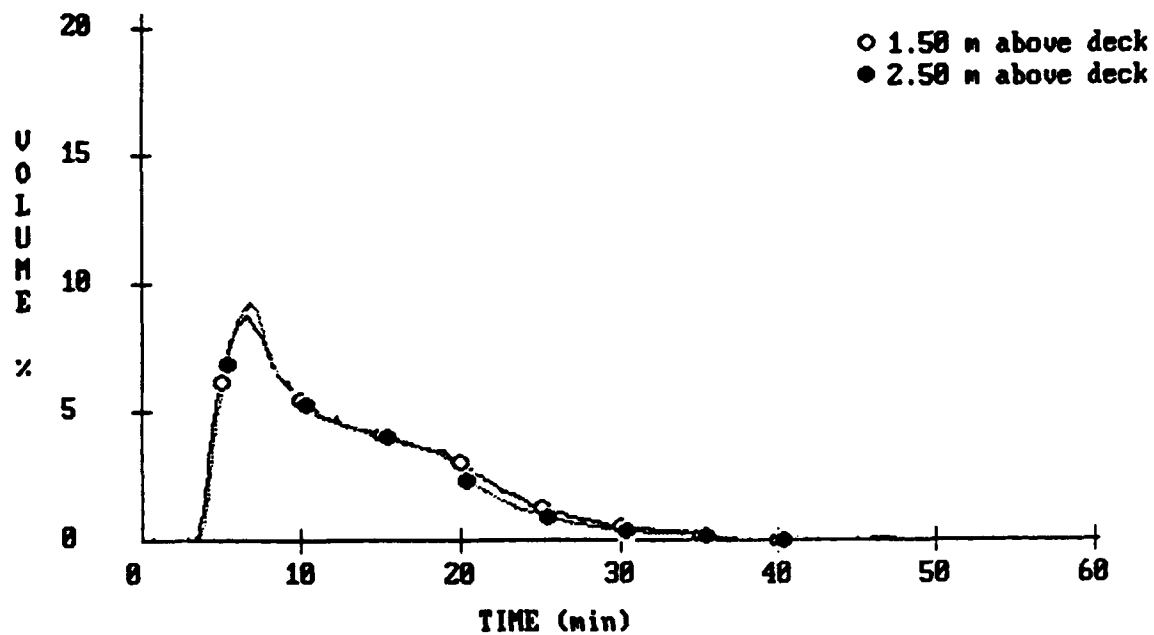


Fig. B-131- CO2 concentration in BERTHING 1 (3-76-2) during Test # 15

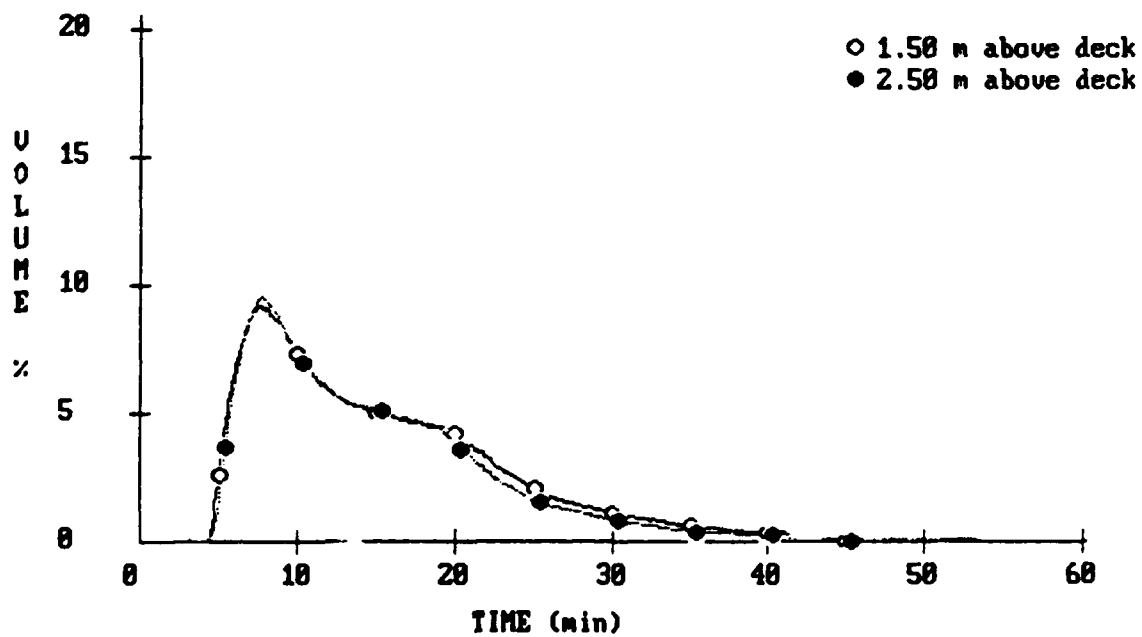


Fig. B-132- CO2 concentration in BERTHING 1 (3-76-2) during Test # 16

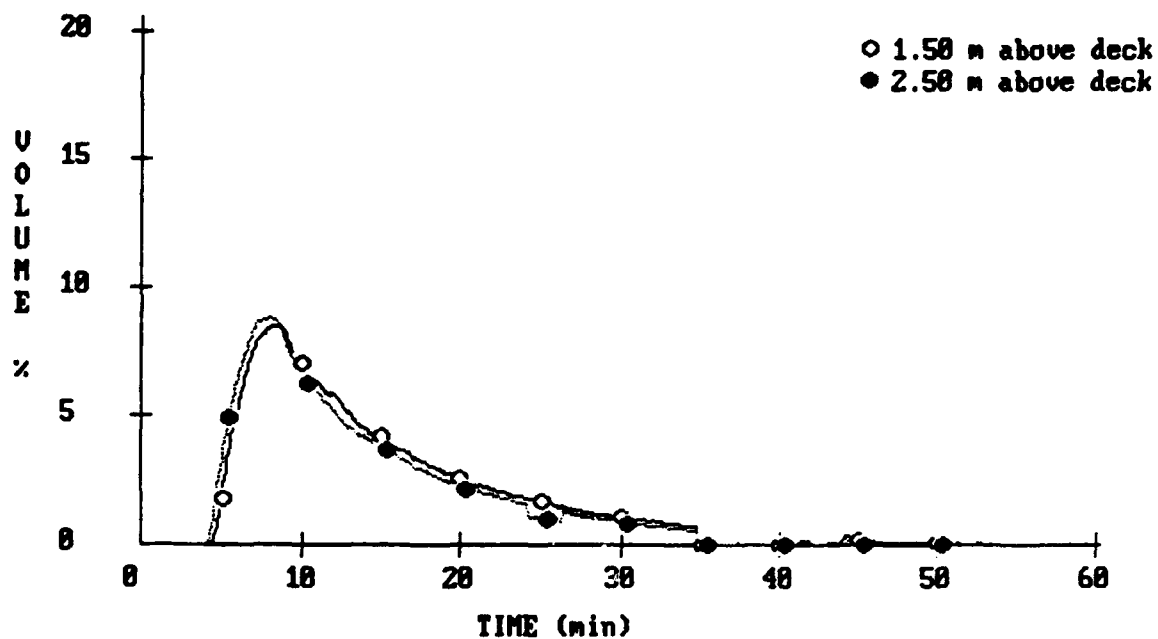


Fig. B-133- CO2 concentration in BERTHING 1 (3-76-2) during Test # 17

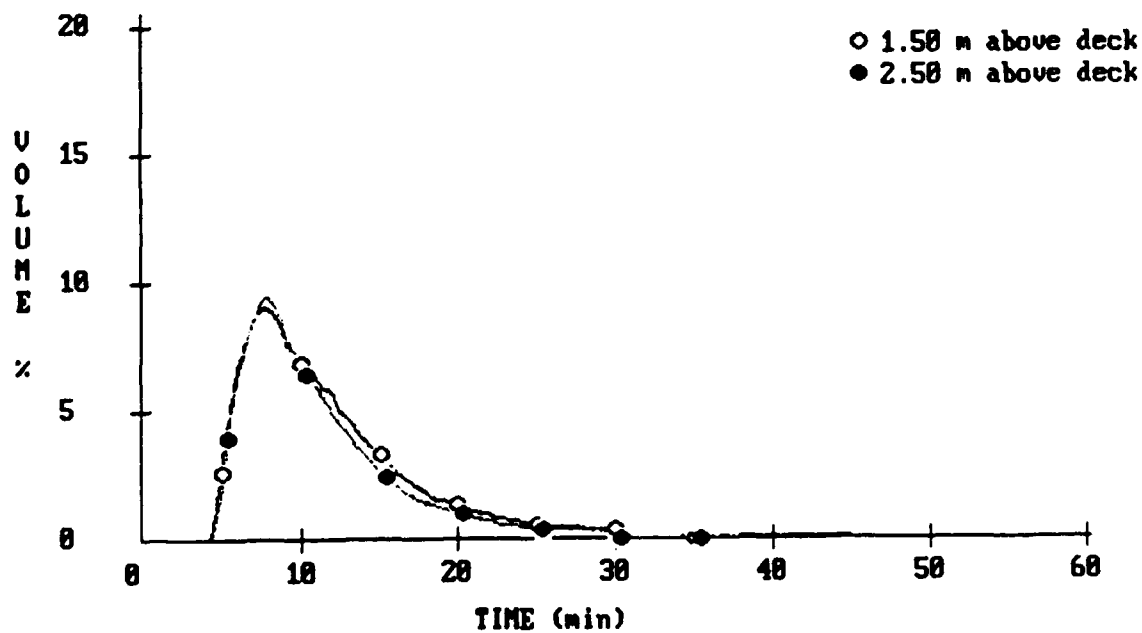


Fig. B-134- CO2 concentration in BERTHING 1 (3-76-2) during Test # 18

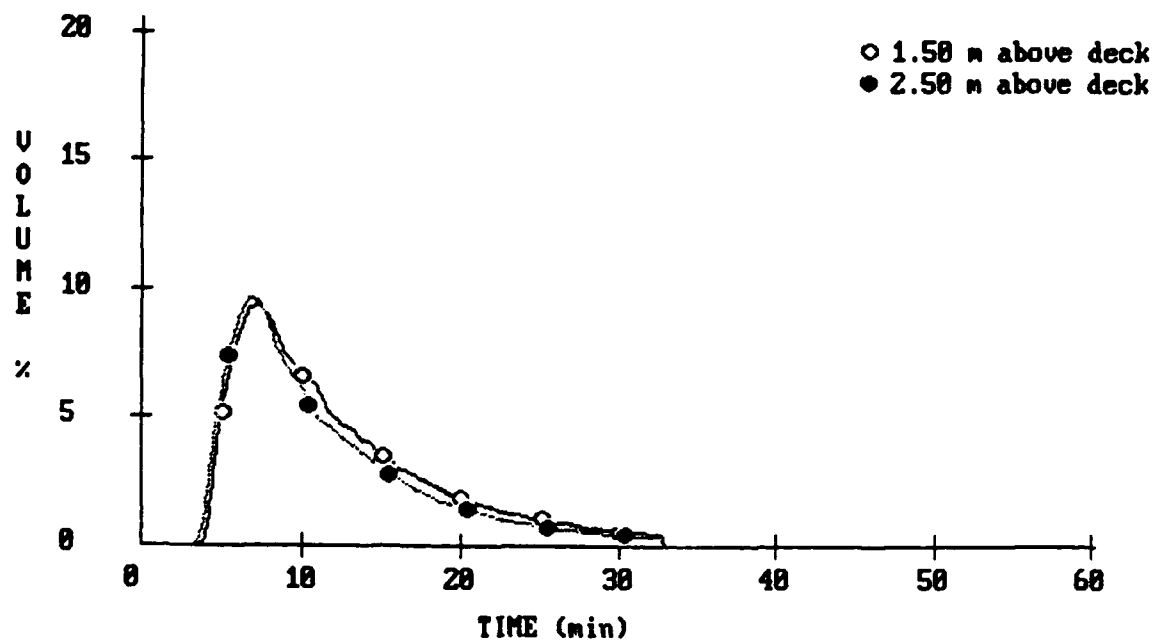


Fig. B-135- CO2 concentration in BERTHING 1 (3-76-2) during Test # 19

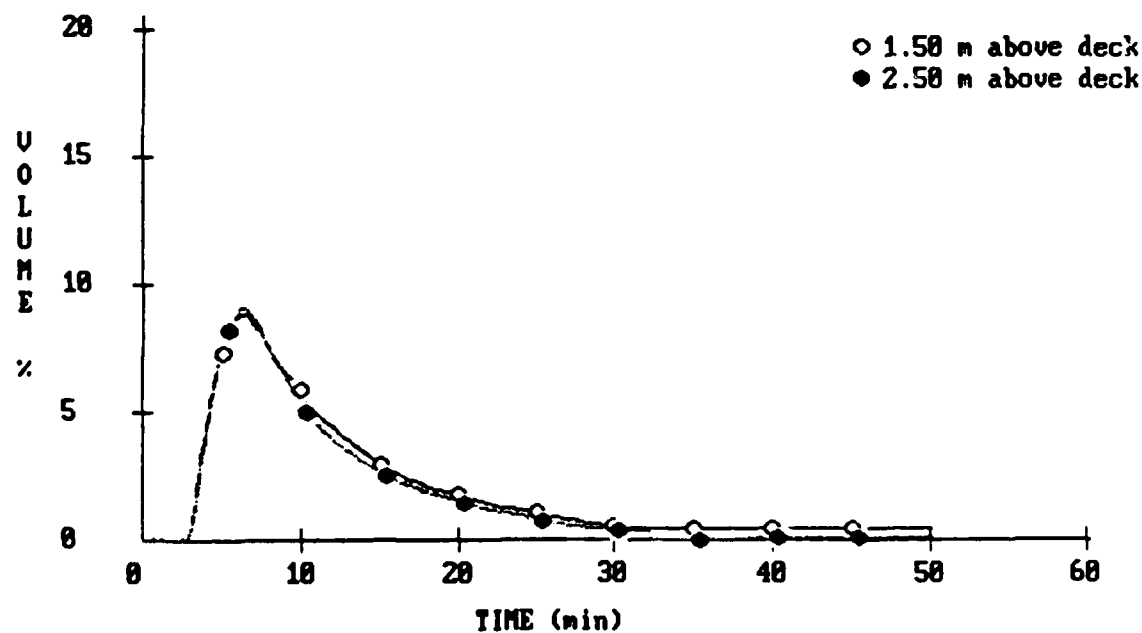


Fig. B-136- CO2 concentration in BERTHING 1 (3-76-2) during Test # 20



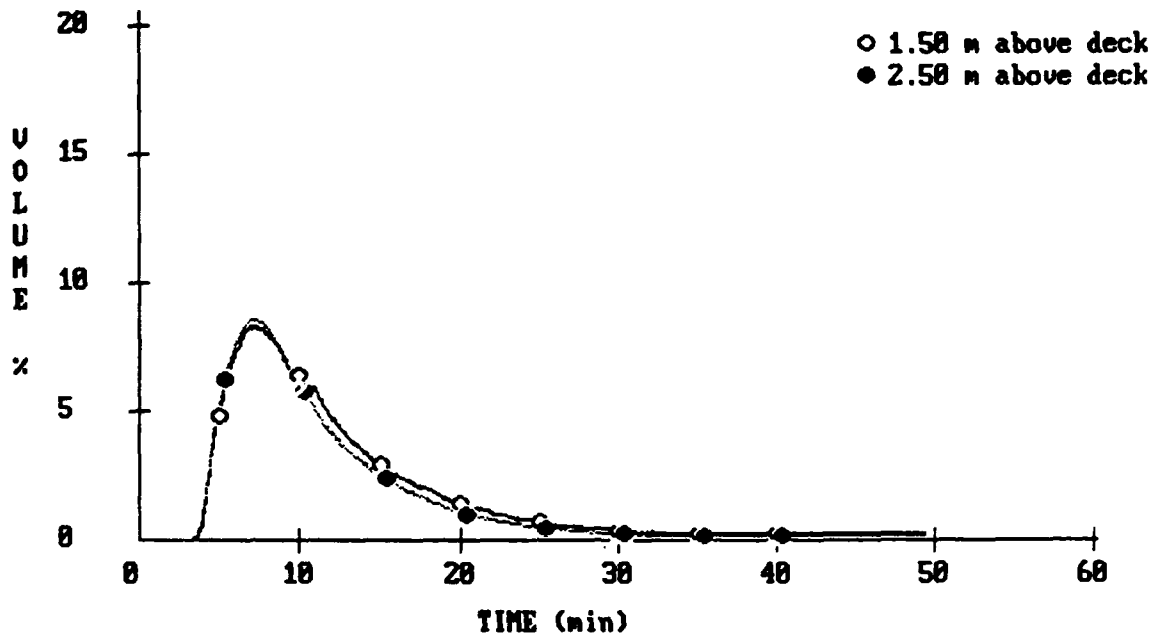


Fig. B-137- CO2 concentration in BERTHING 1 (3-76-2) during Test # 21

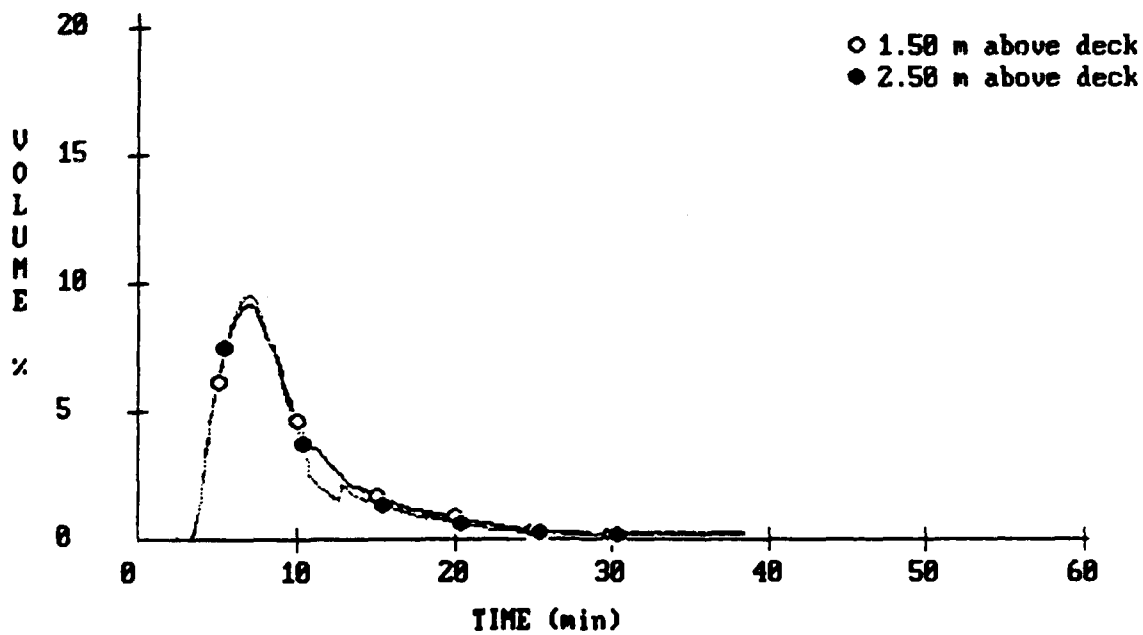


Fig. B-138- CO2 concentration in BERTHING 1 (3-76-2) during Test # 22

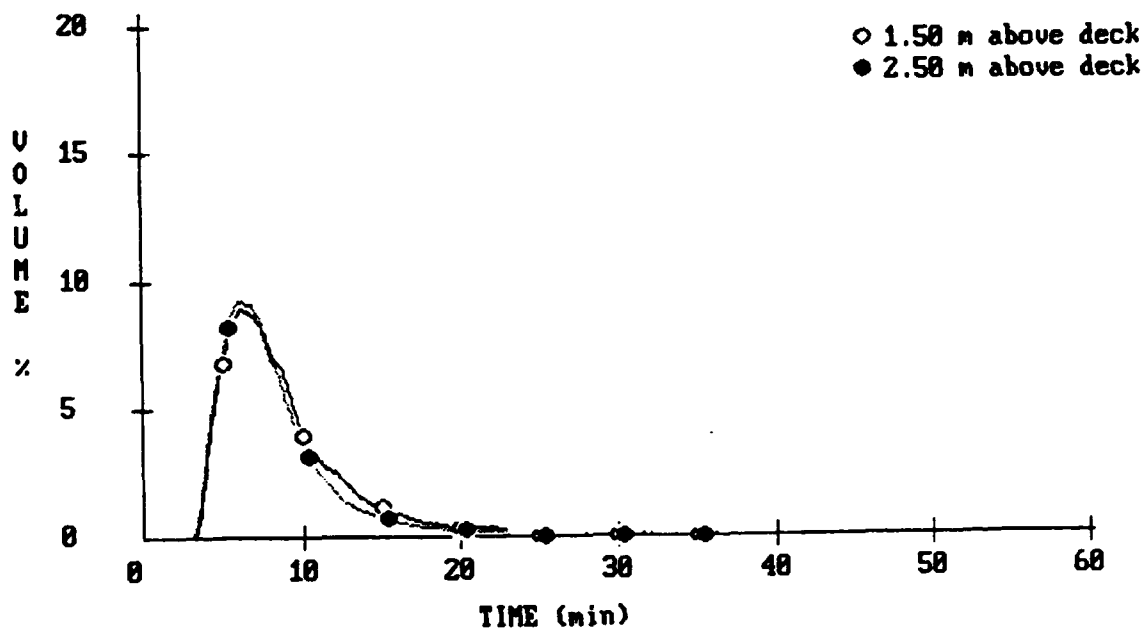


Fig. B-139- CO2 concentration in BERTHING 1 (3-76-2) during Test # 23

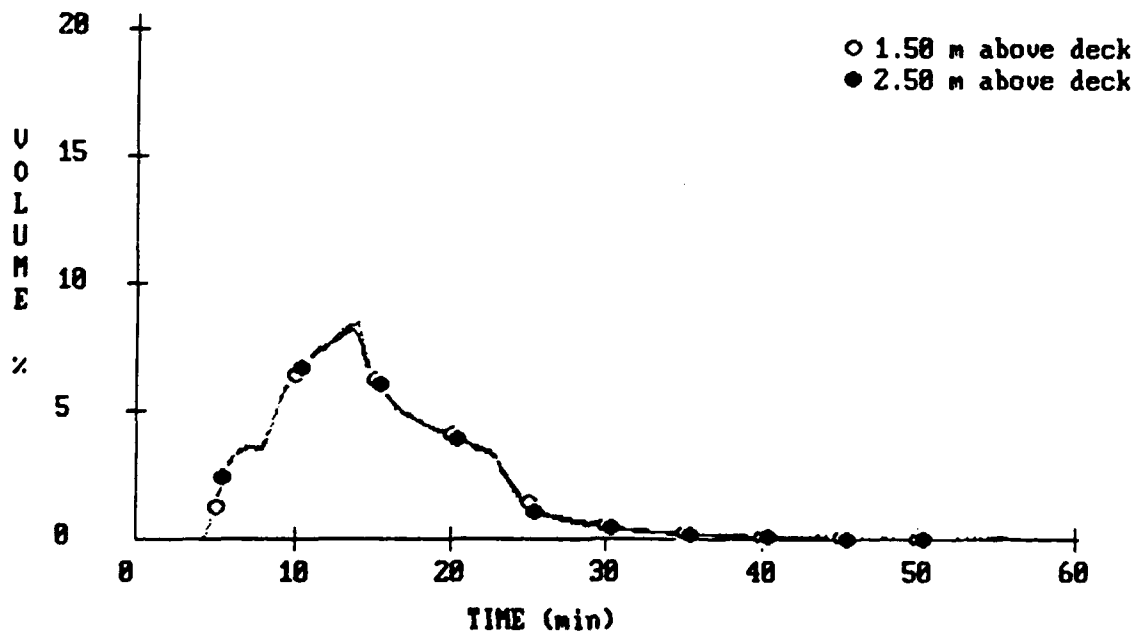


Fig. B-140- CO2 concentration in BERTHING 1 (3-76-2) during Test # 24

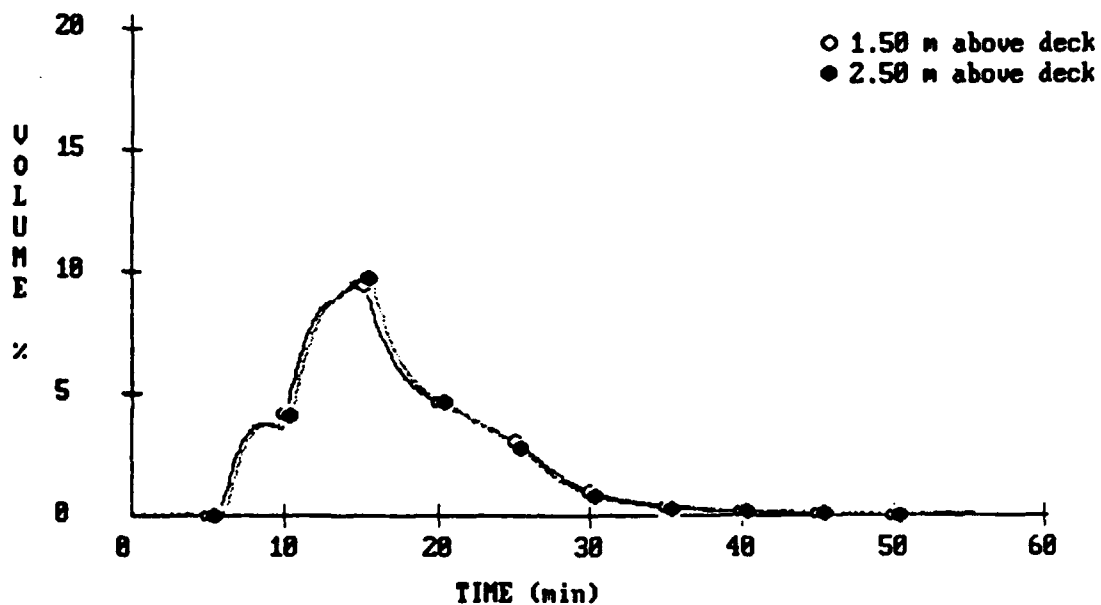


Fig. B-141- CO2 concentration in BERTHING 1 (3-76-2) during Test # 25

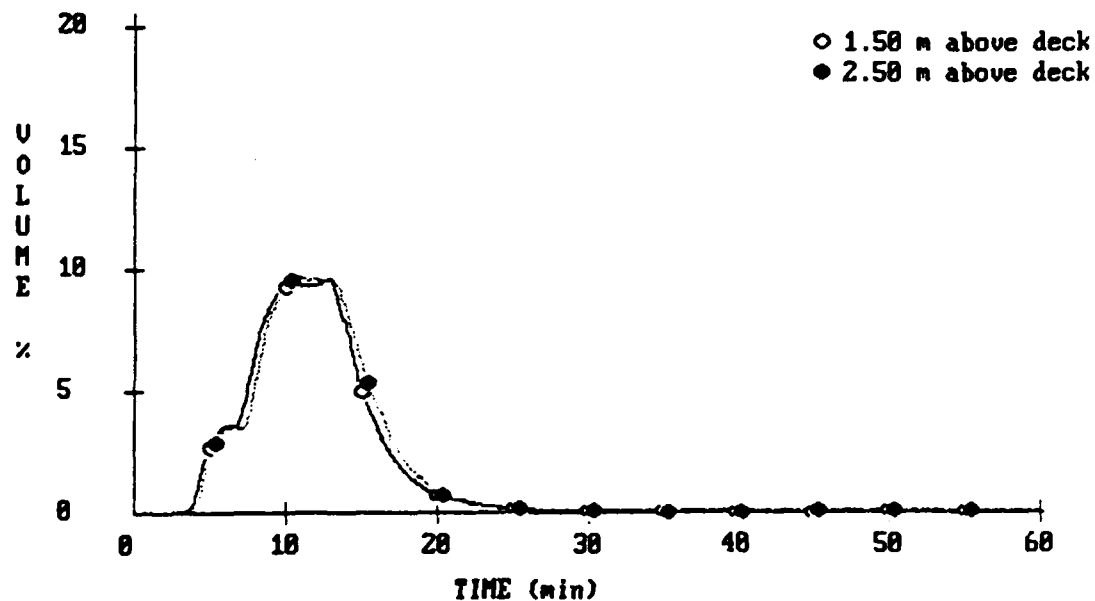


Fig. B-142- CO2 concentration in BERTHING 1 (3-76-2) during Test # 26

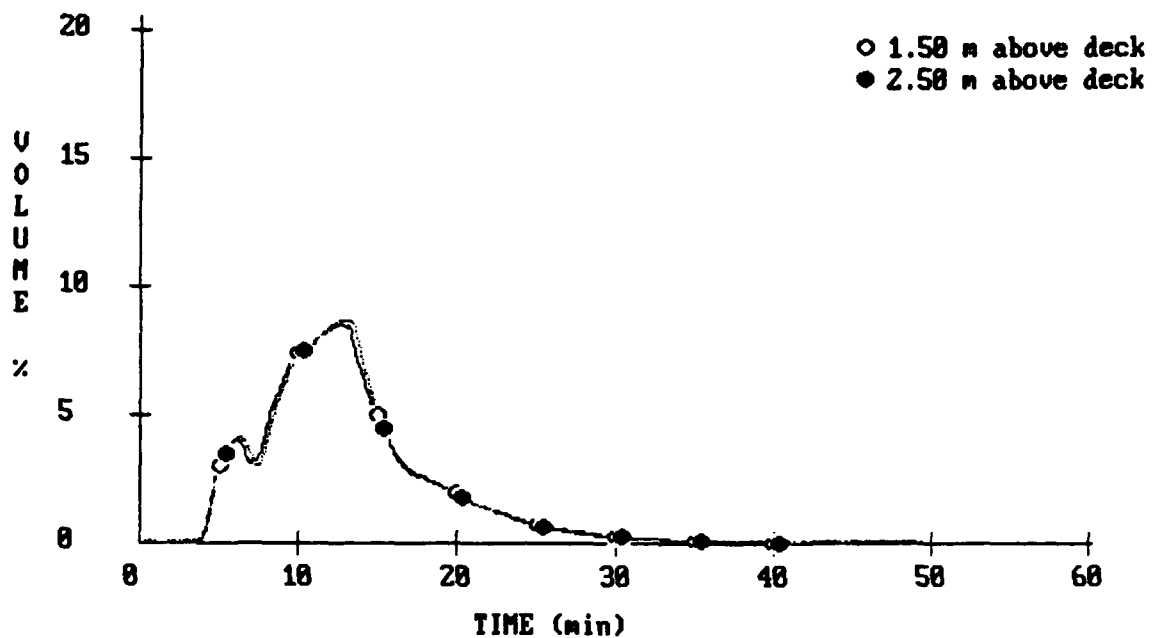


Fig. B-143- CO<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 27

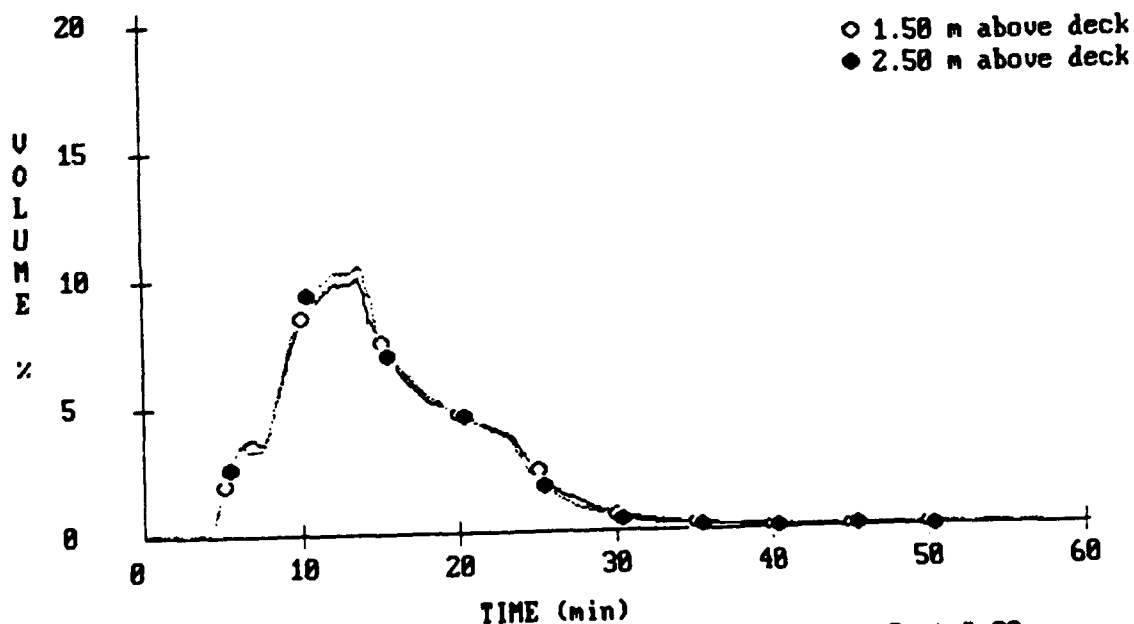


Fig. B-144- CO<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 28

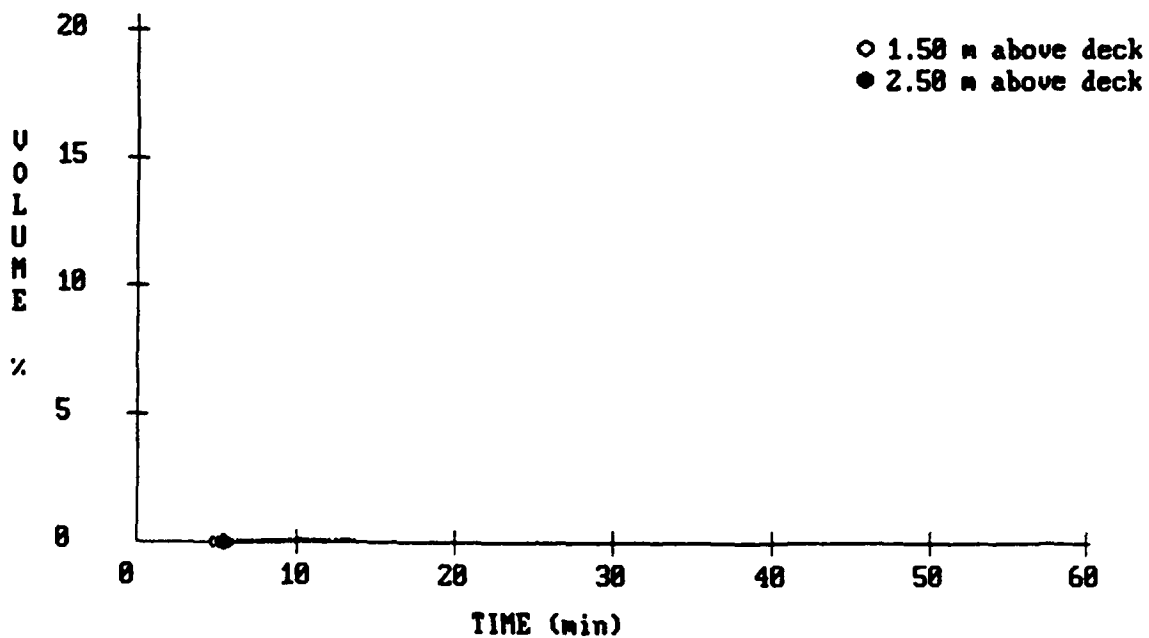


Fig. B-145- CO2 concentration in BERTHING 1 (3-76-2) during Test # 29

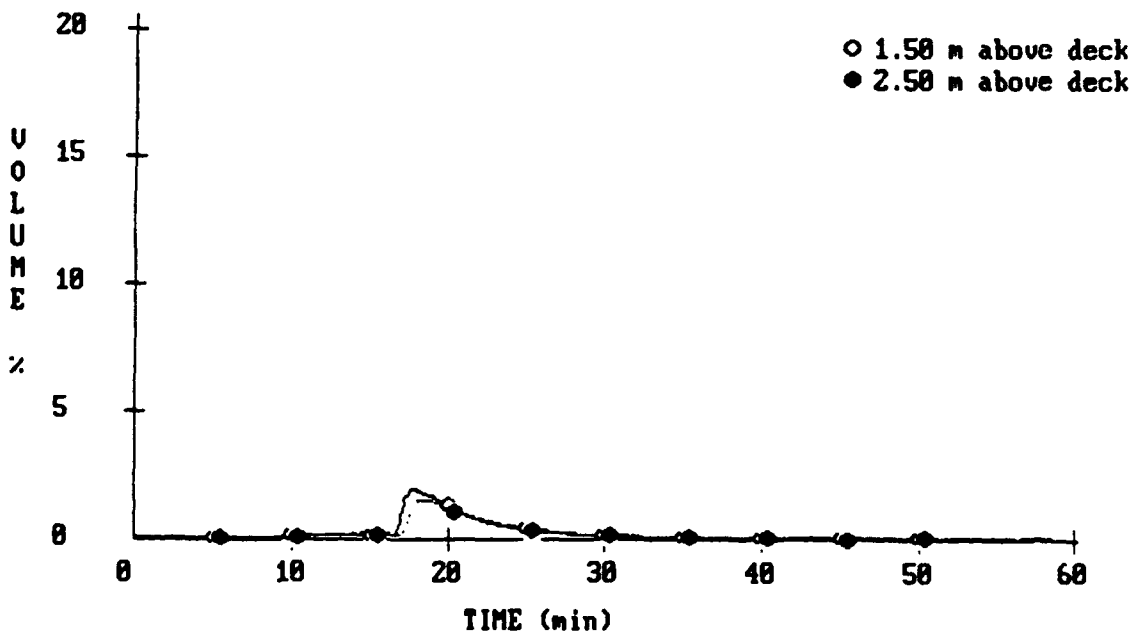


Fig. B-146- CO2 concentration in BERTHING 1 (3-76-2) during Test # 30

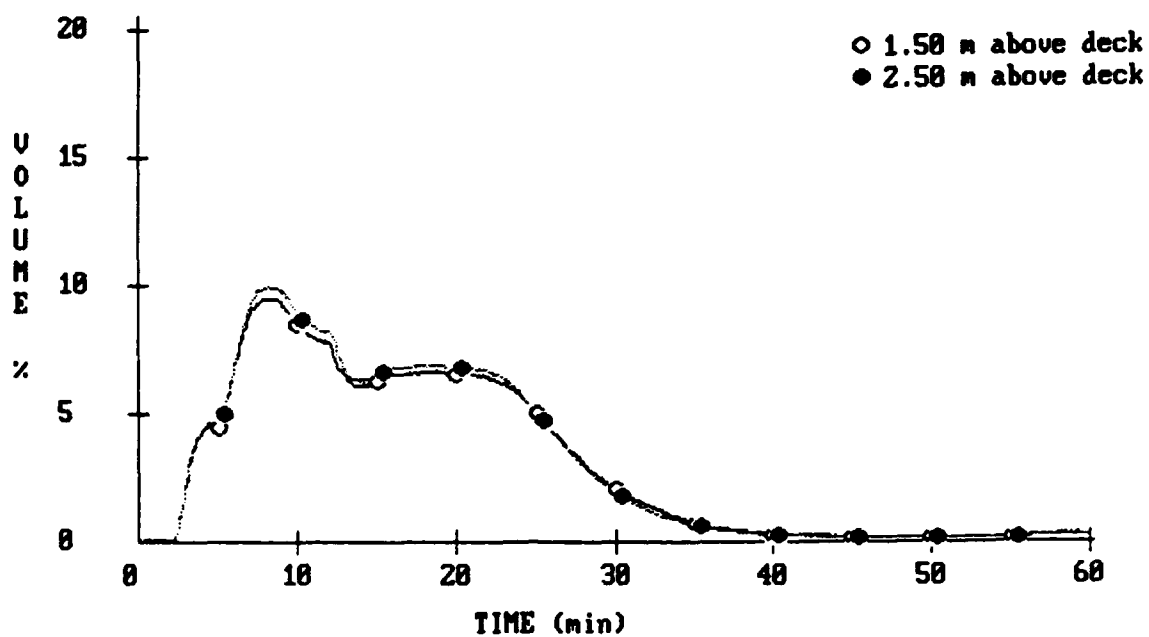


Fig. B-147- CO2 concentration in BERTHING 1 (3-76-2) during Test # 31

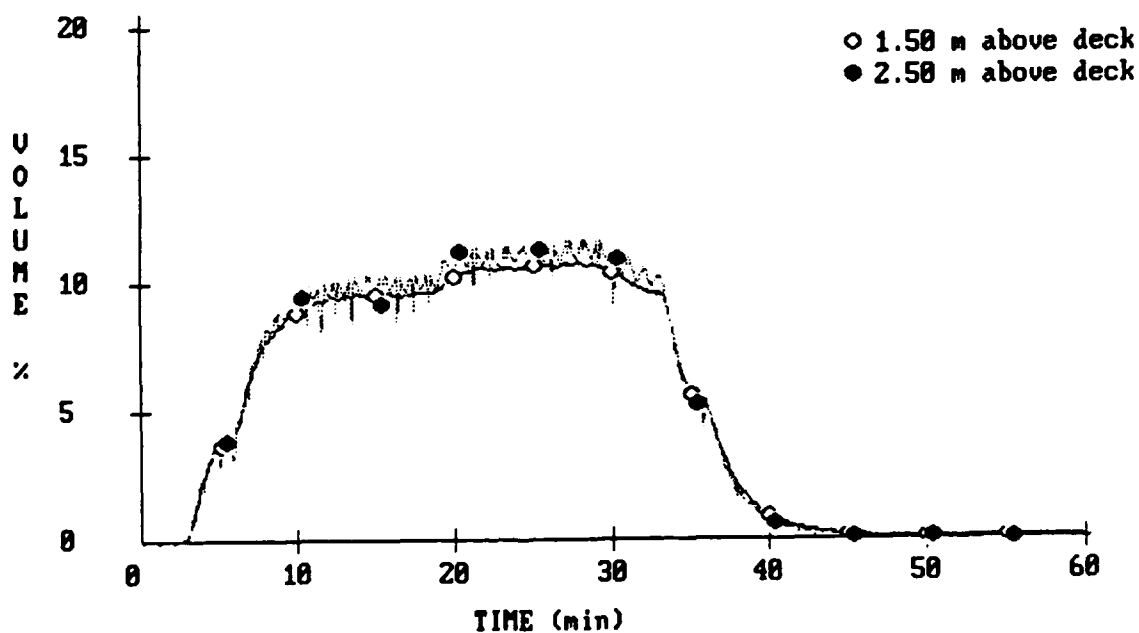


Fig. B-148- CO2 concentration in BERTHING 1 (3-76-2) during Test # 32

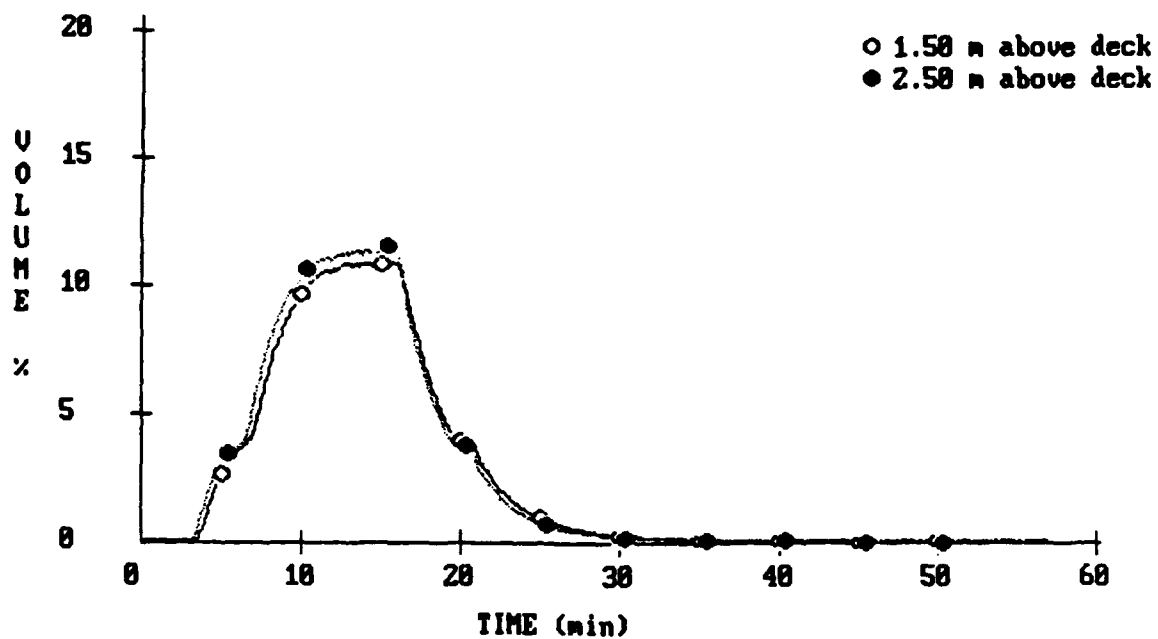


Fig. B-149- CO2 concentration in BERTHING 1 (3-76-2) during Test # 33

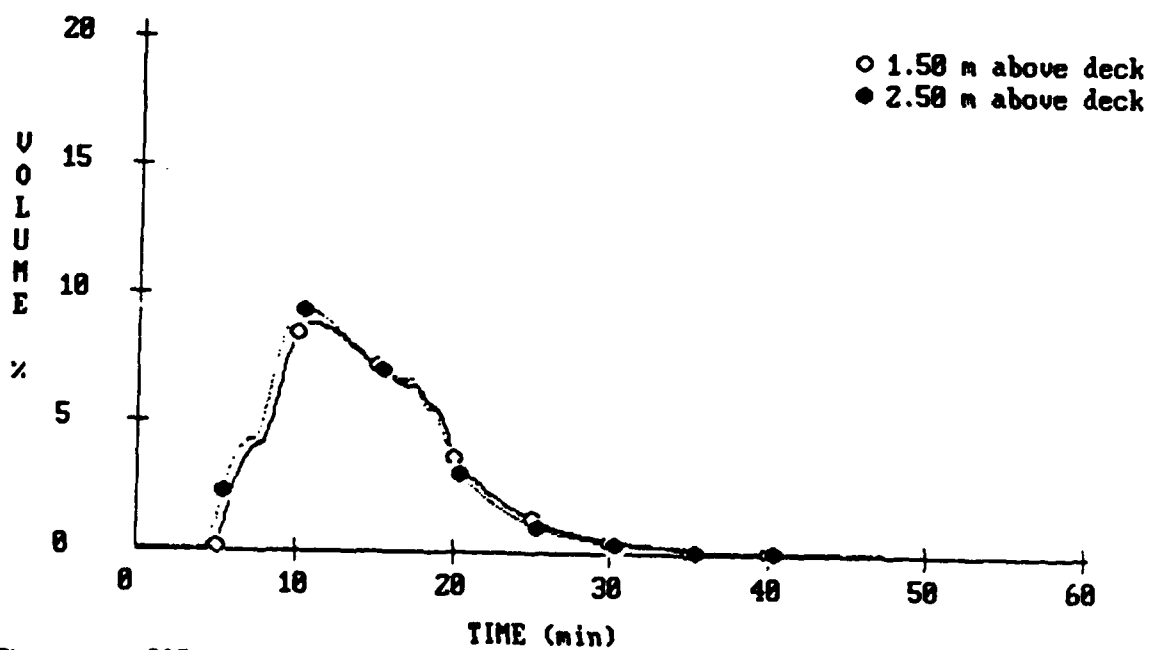


Fig. B-150- CO2 concentration in BERTHING 1 (3-76-2) during Test # 34

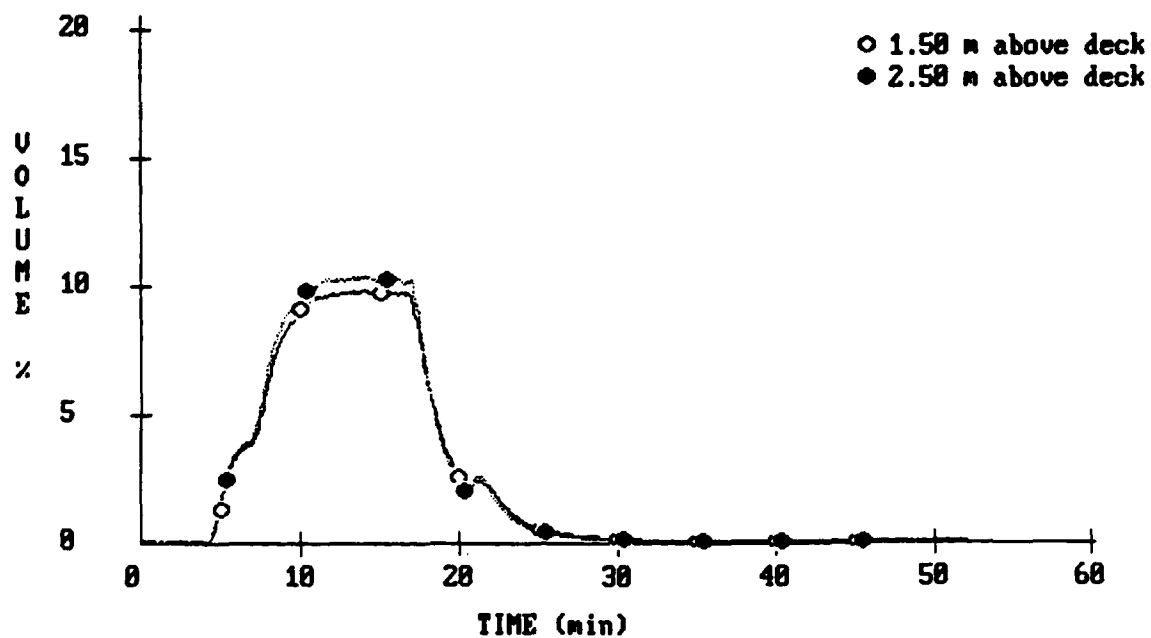


Fig. B-151- CO2 concentration in BERTHING 1 (3-76-2) during Test # 35

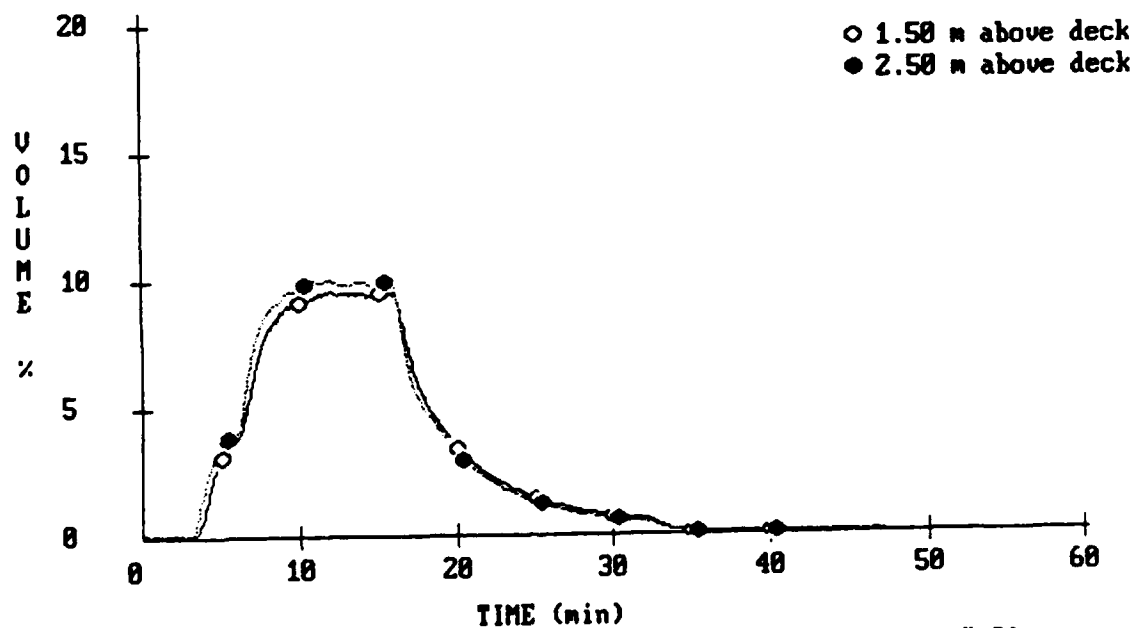


Fig. B-152- CO2 concentration in BERTHING 1 (3-76-2) during Test # 36



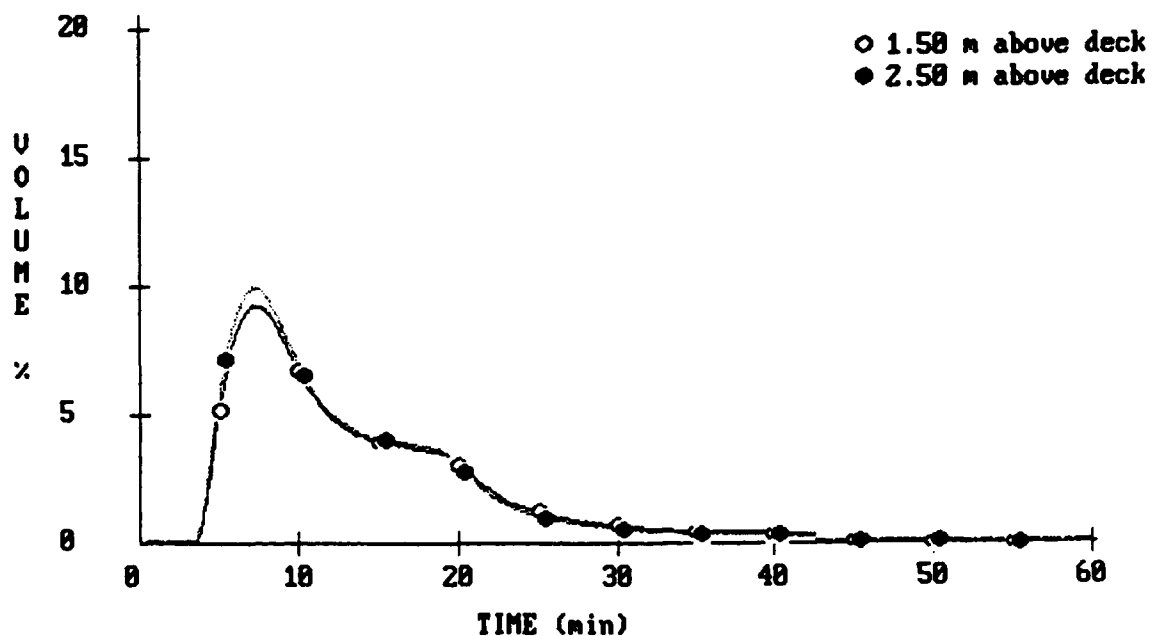


Fig. B-153- CO2 concentration in BERTHING 1 (3-76-2) during Test # 37

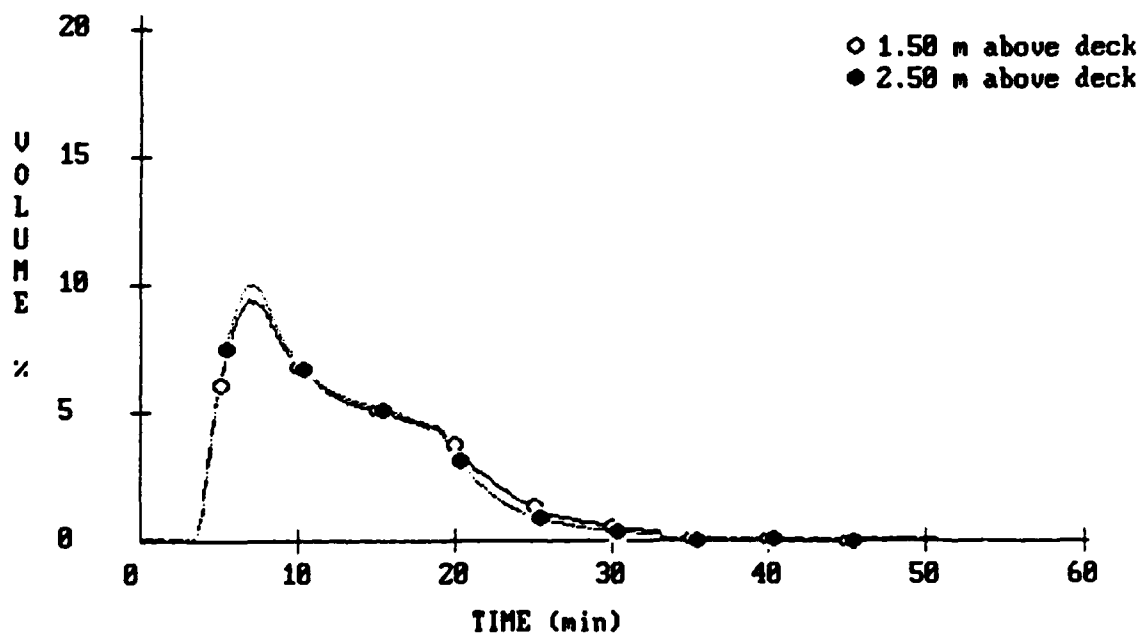


Fig. B-154- CO2 concentration in BERTHING 1 (3-76-2) during Test # 38

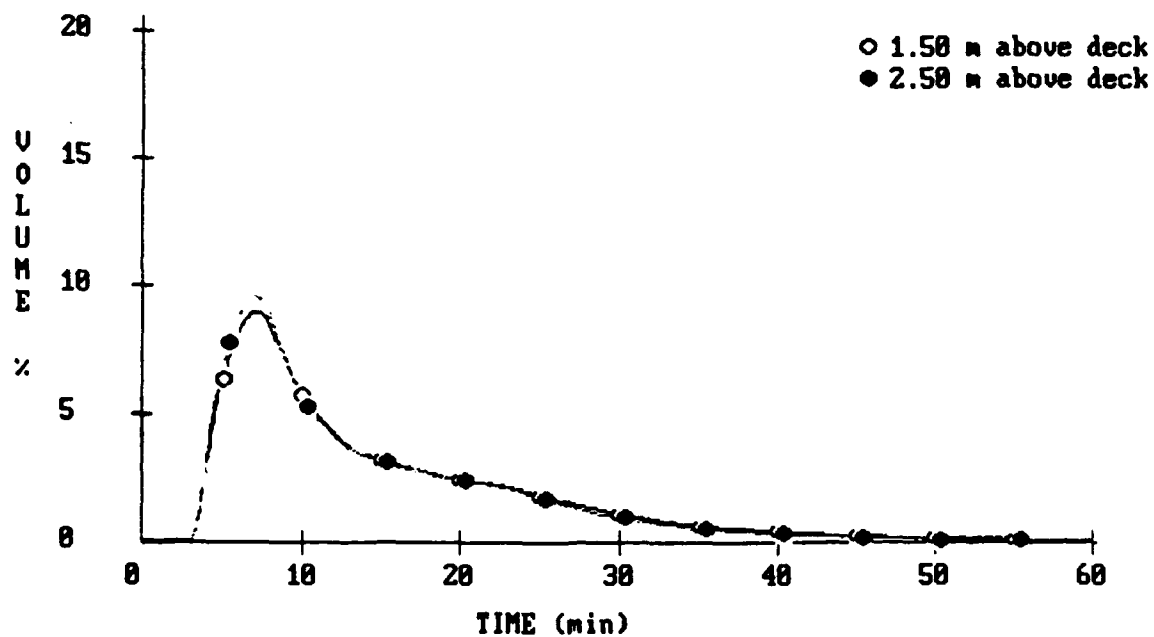


Fig. B-155- CO2 concentration in BERTHING 1 (3-76-2) during Test # 39

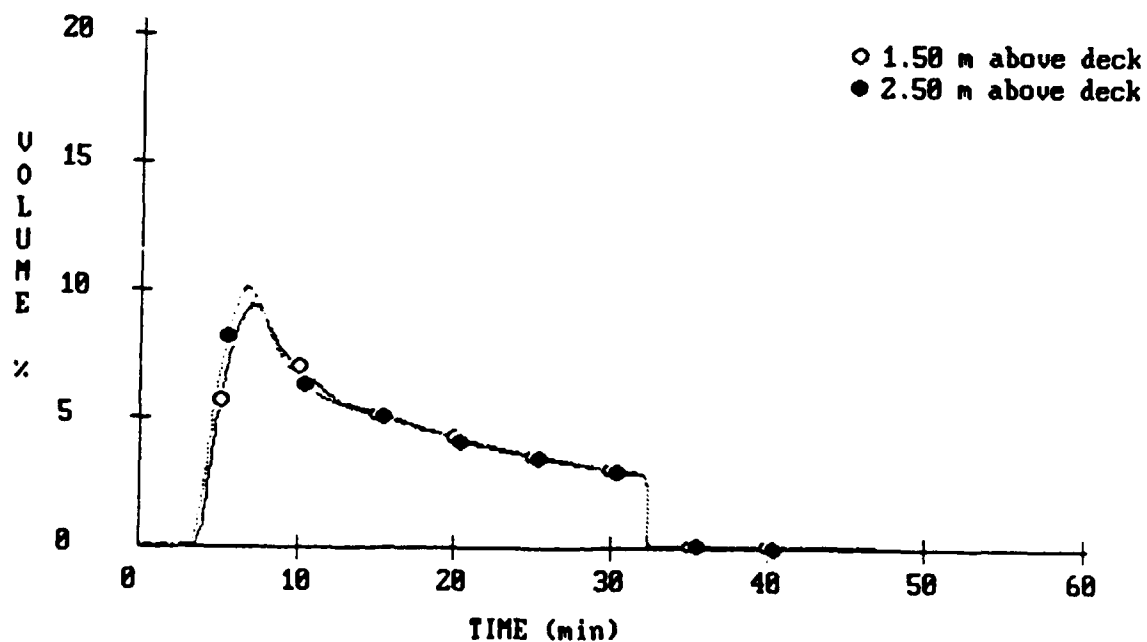


Fig. B-156- CO2 concentration in BERTHING 1 (3-76-2) during Test # 40

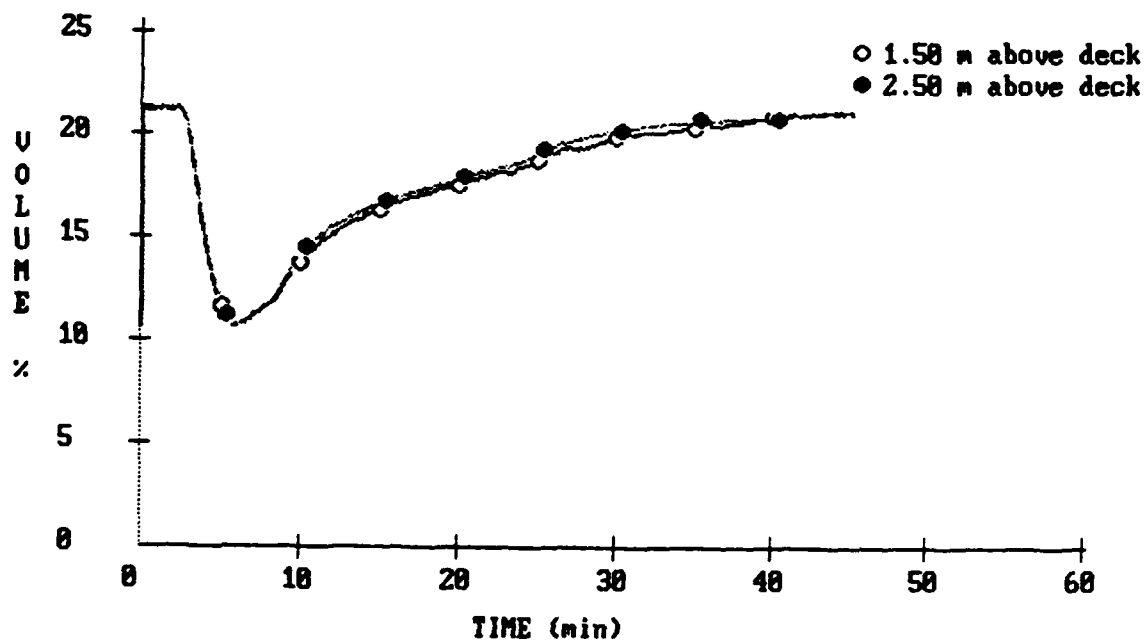


Fig. B-157- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 2

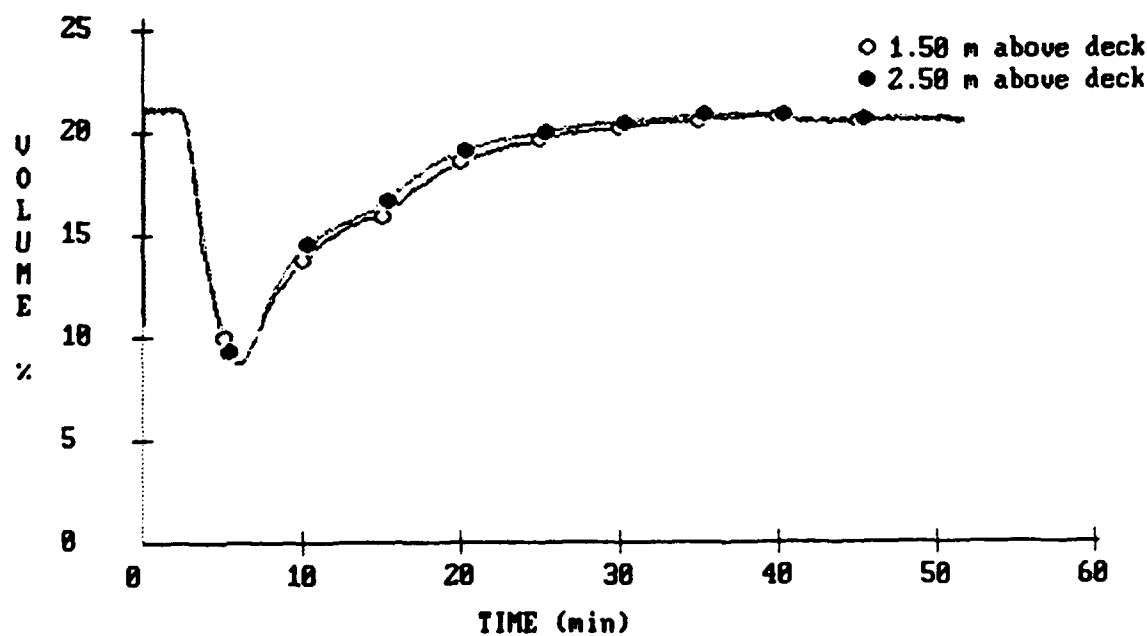


Fig. B-158- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 3

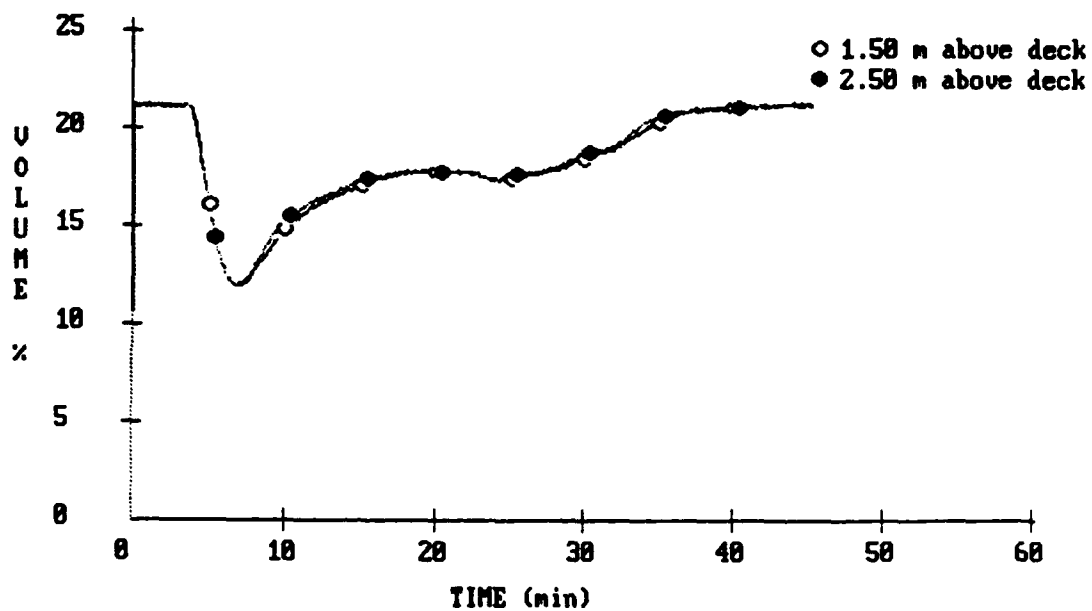


Fig. B-159- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 4

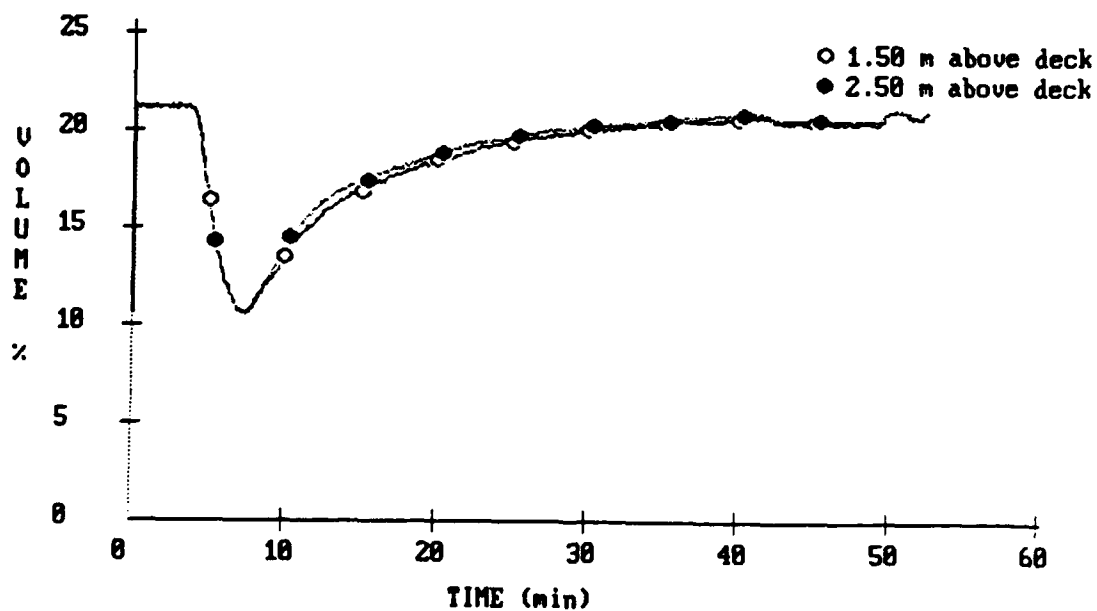


Fig. B-160- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 5

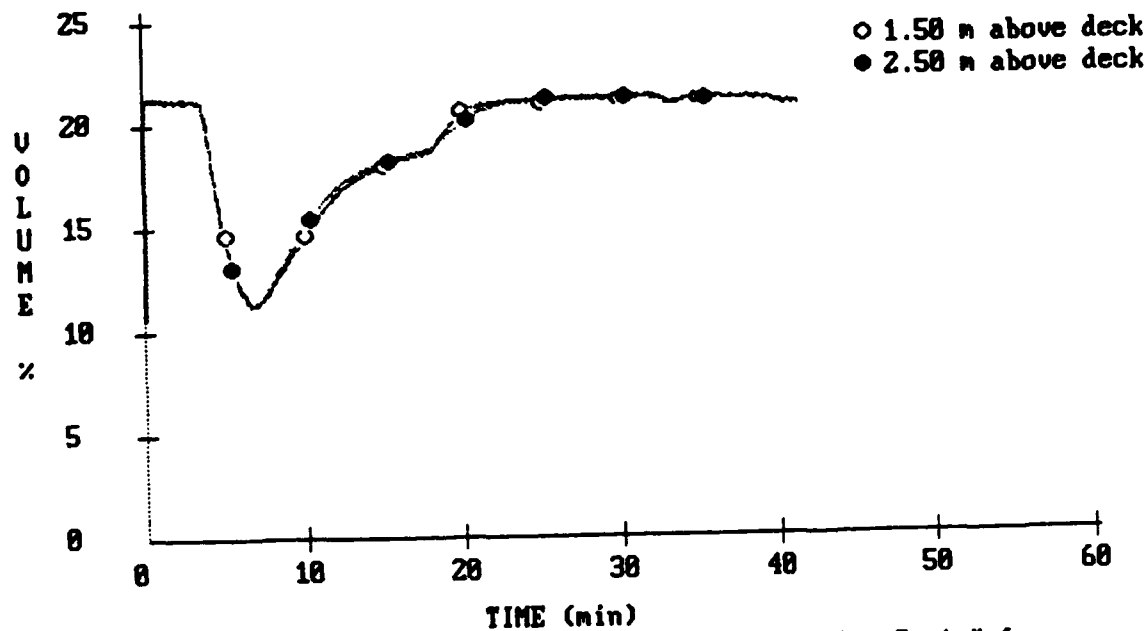


Fig. B-161- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 6

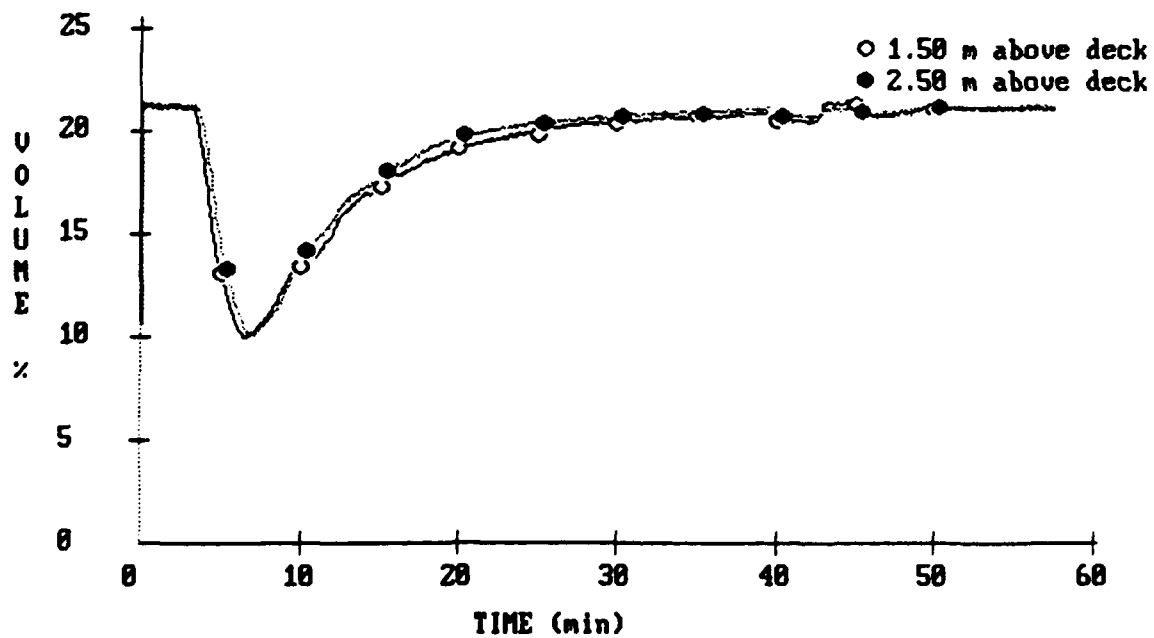


Fig. B-162- concentration in BERTHING 1 (3-76-2) during Test # 7

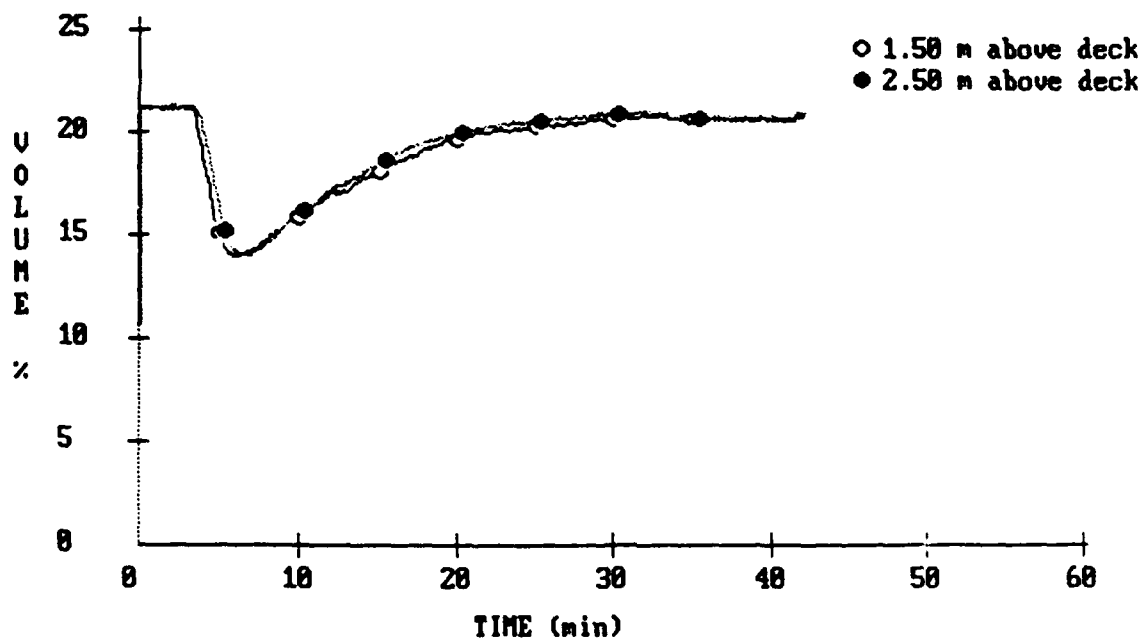


Fig. B-163- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 8

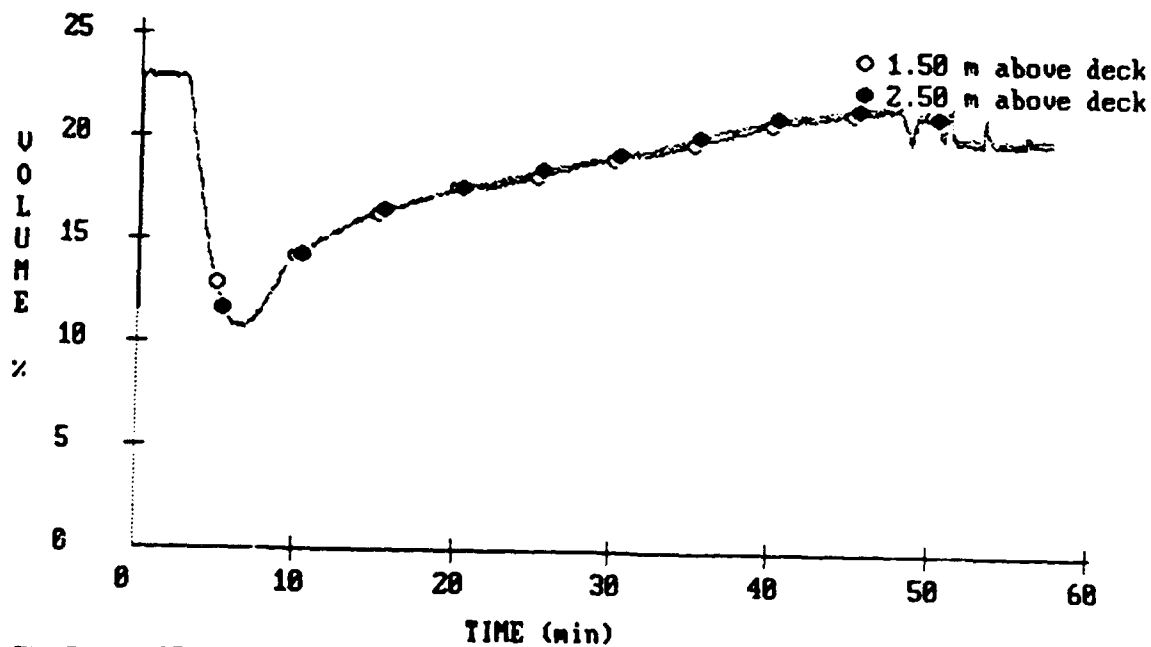


Fig. B-164- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 9

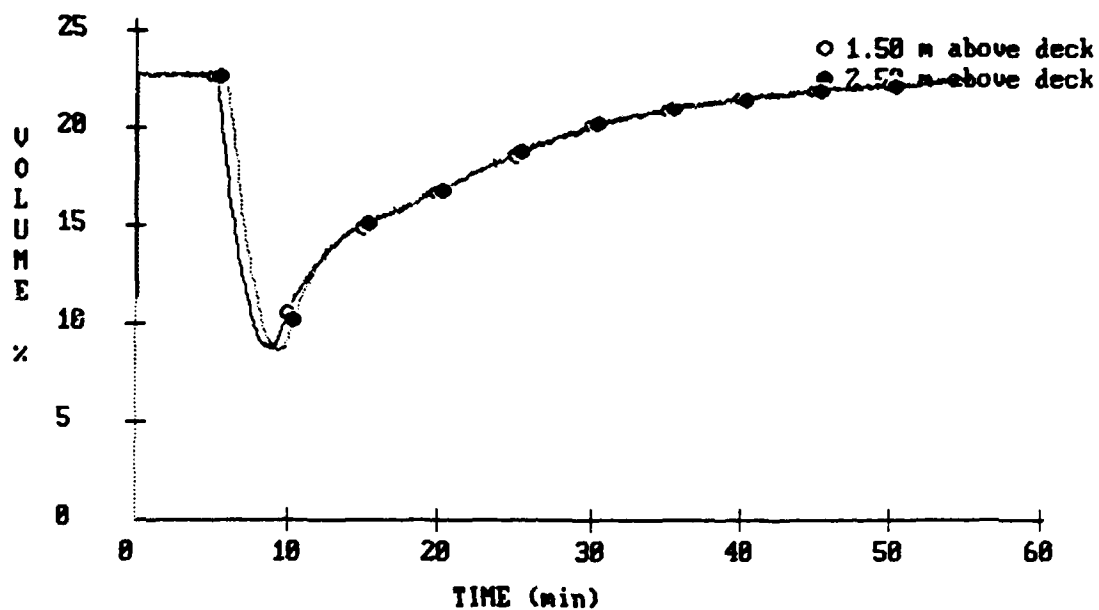


Fig. B-165- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 10

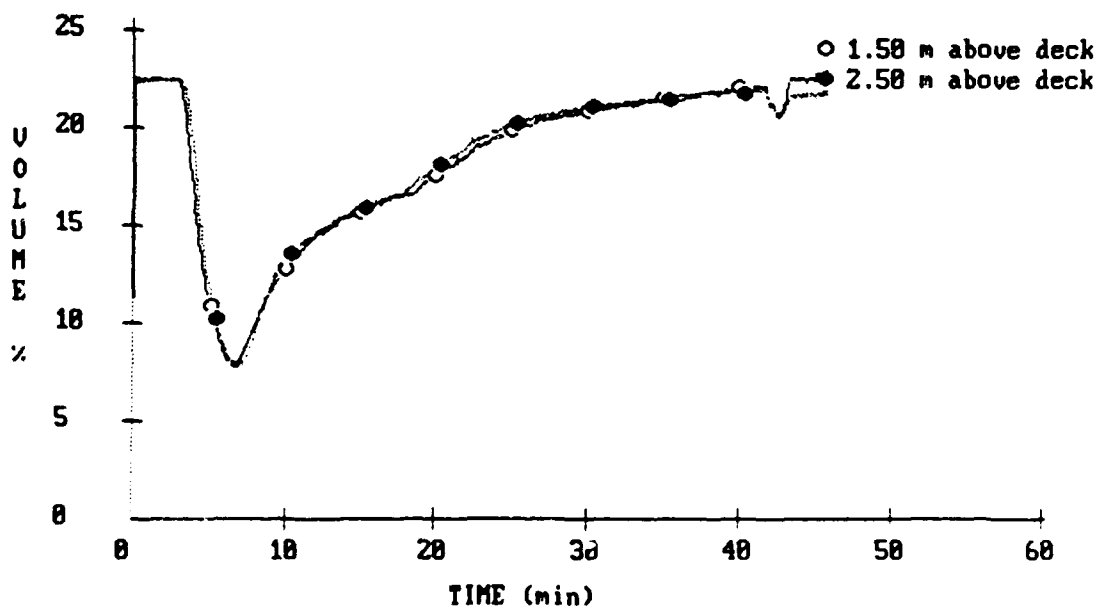


Fig. B-166- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 11

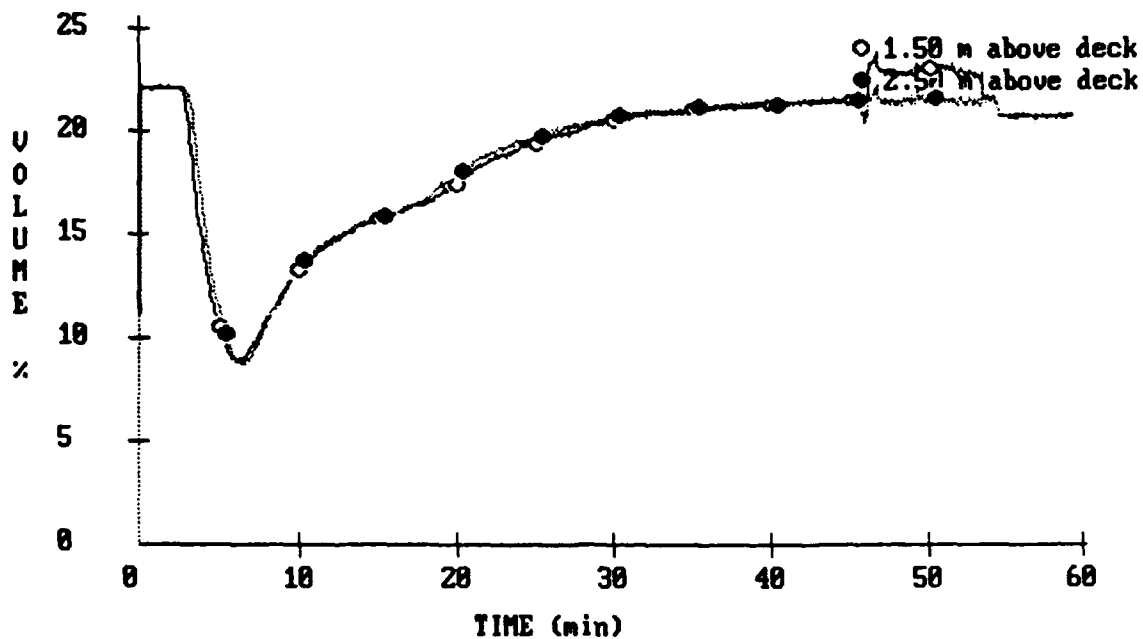


Fig. B-167- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 12

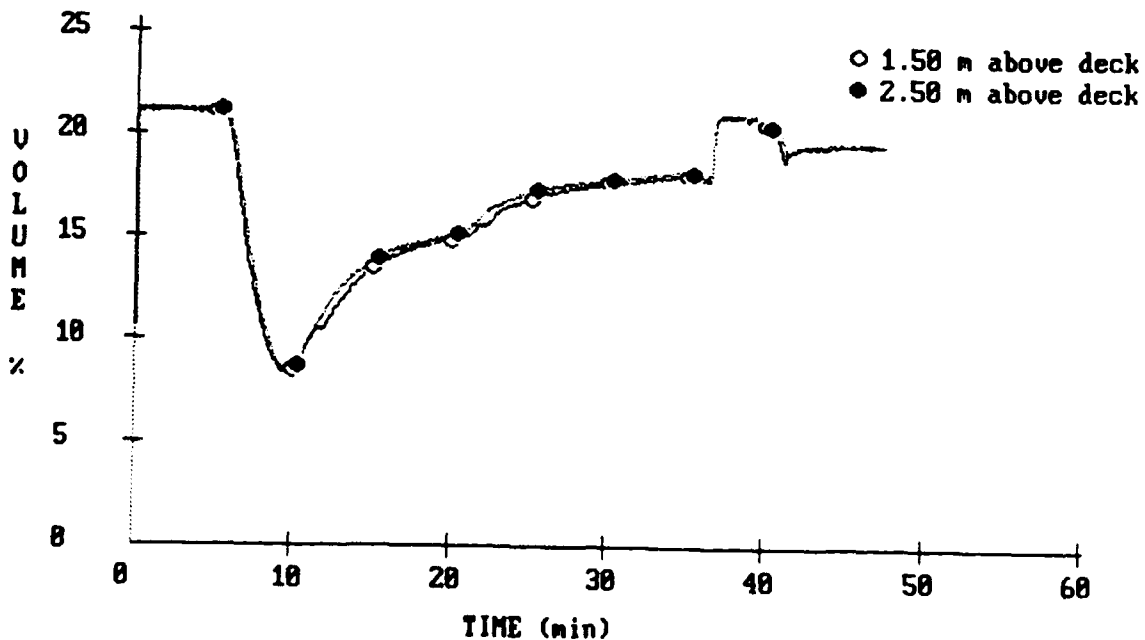


Fig. B-168- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 13



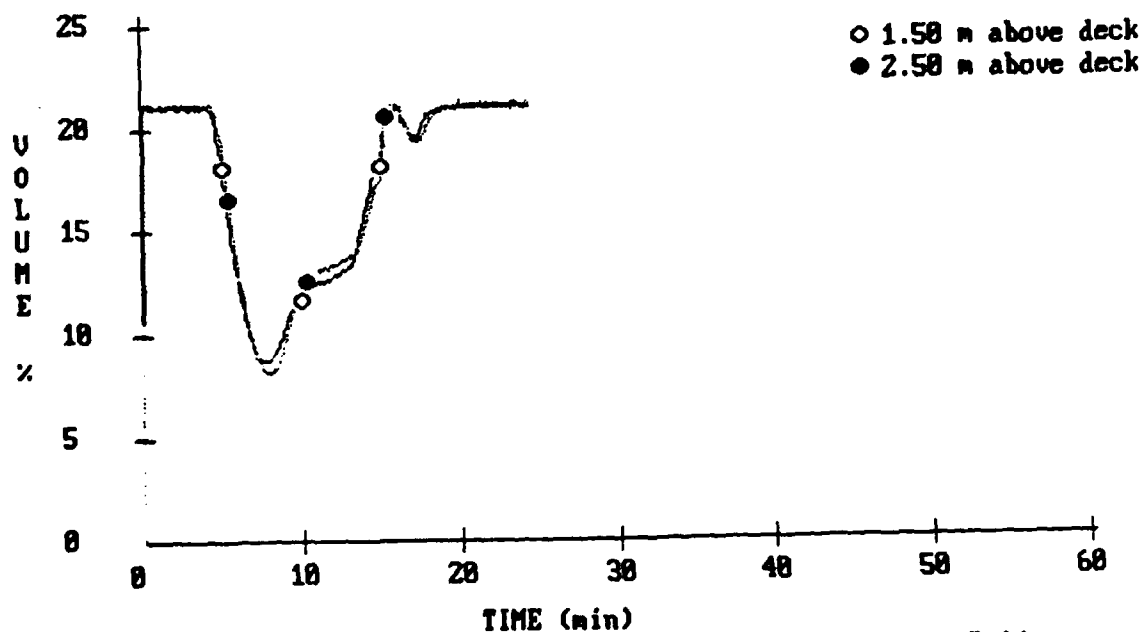


Fig. B-169- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 14

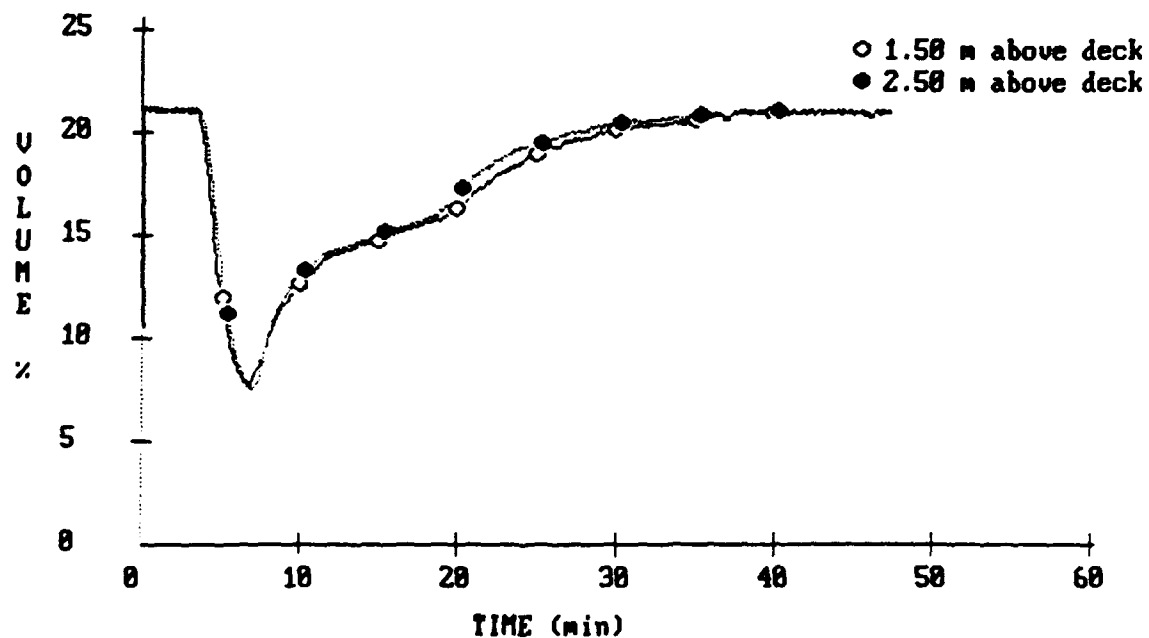


Fig. B-170- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 15

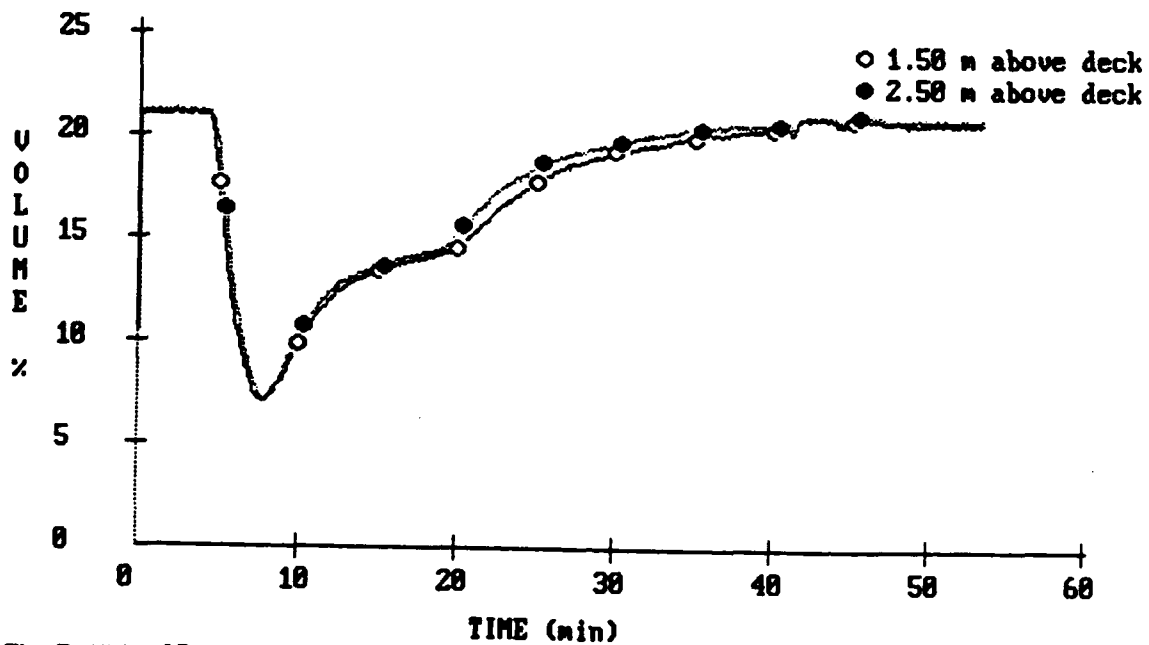


Fig. B-171- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 16

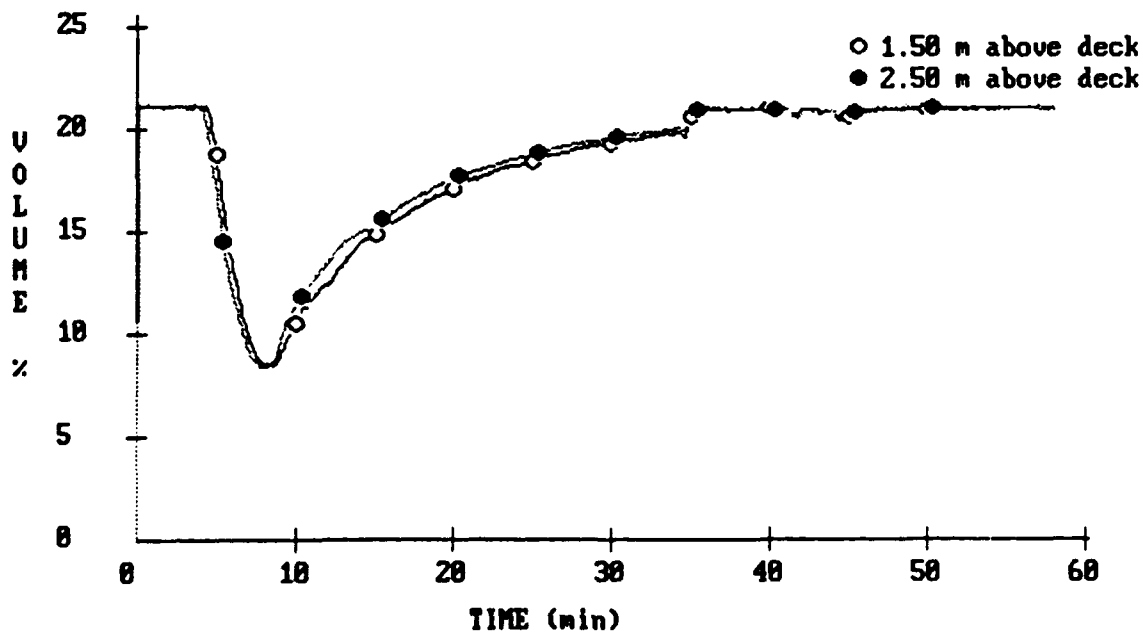


Fig. B-172- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 17

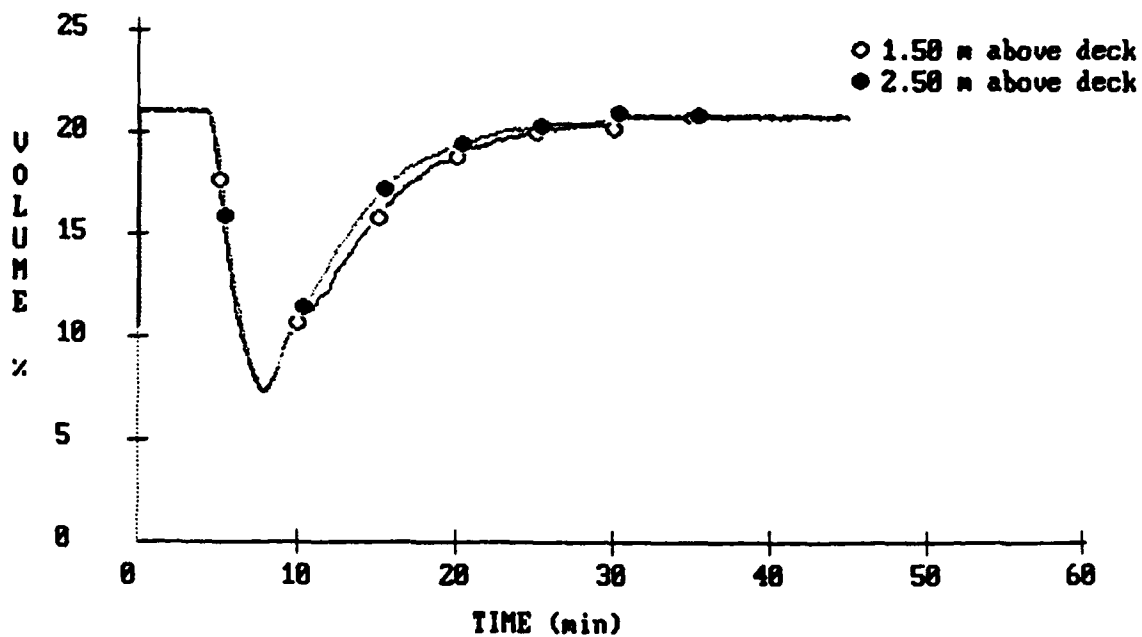


Fig. B-173- concentration in BERTHING 1 (3-76-2) during Test # 18

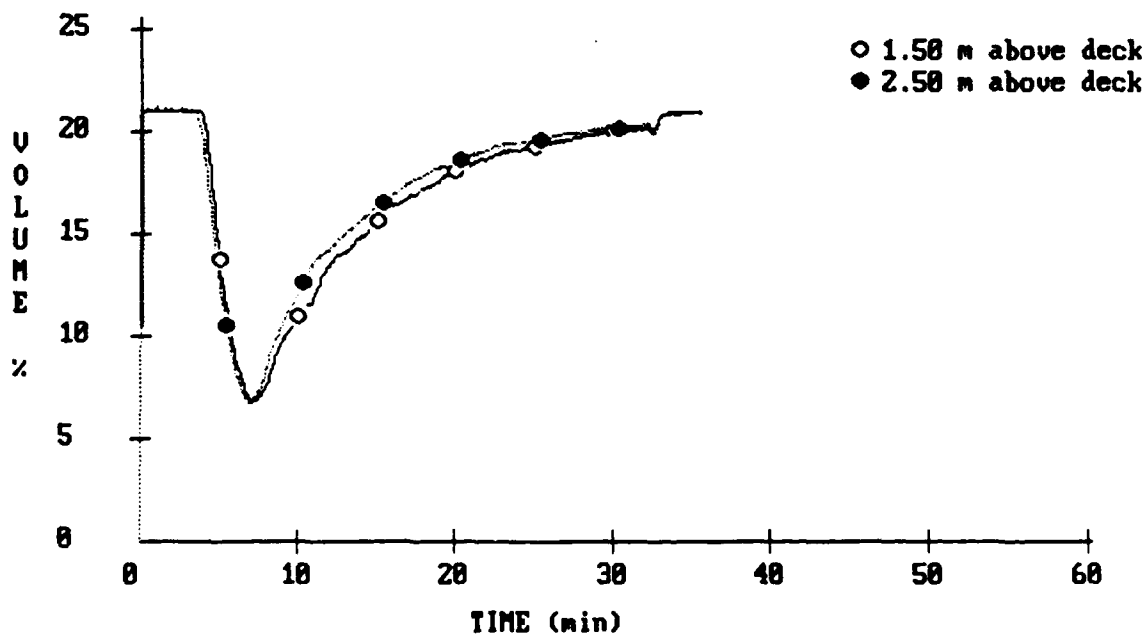


Fig. B-174- O2 concentration in BERTHING 1 (3-76-2) during Test # 19

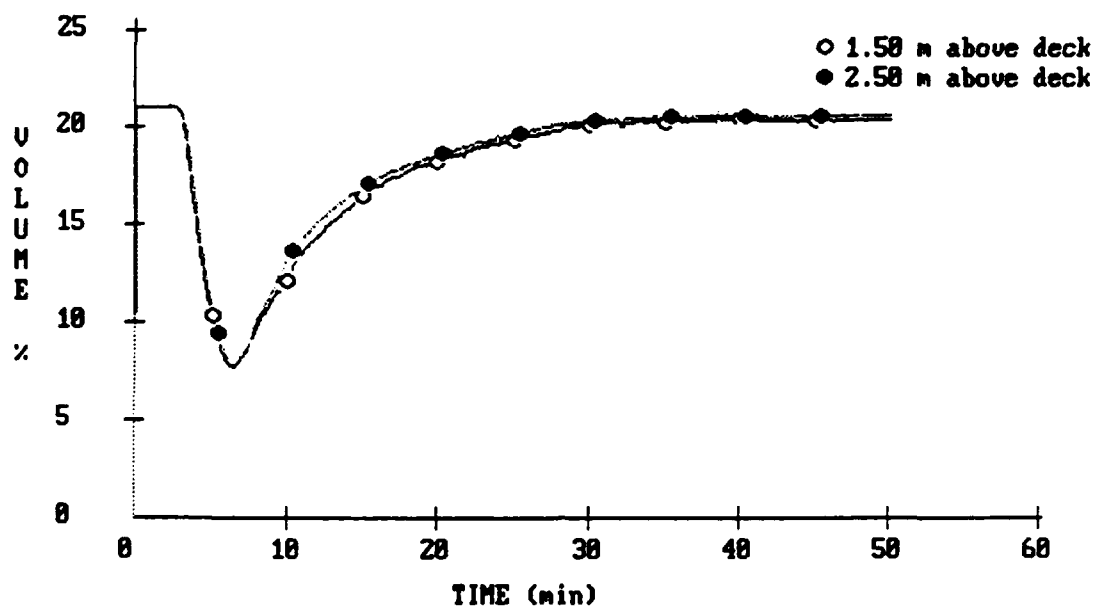


Fig. B-175- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 20

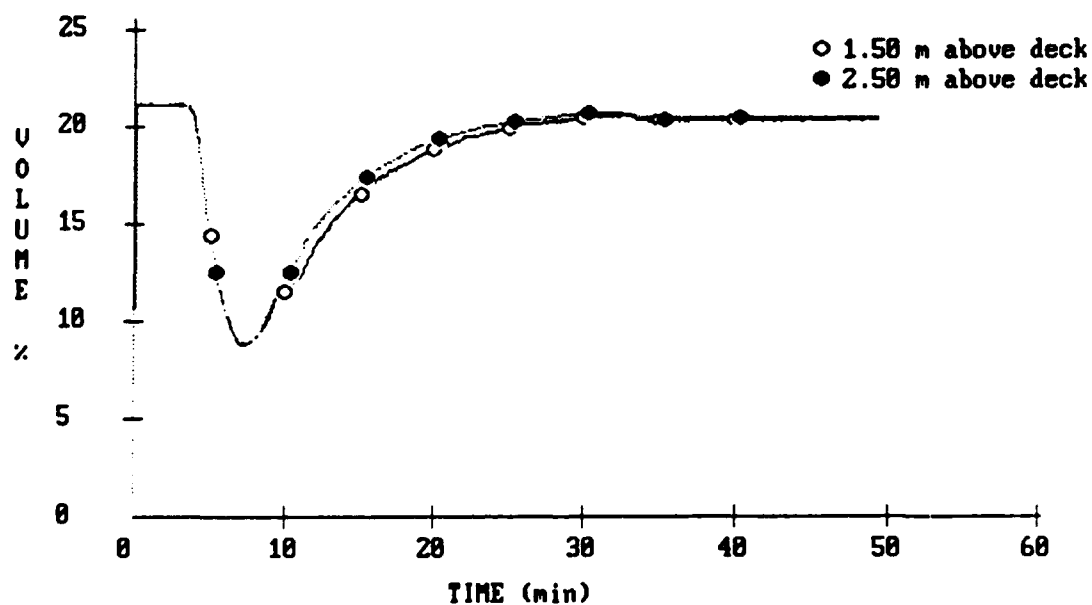


Fig. B-176- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 21

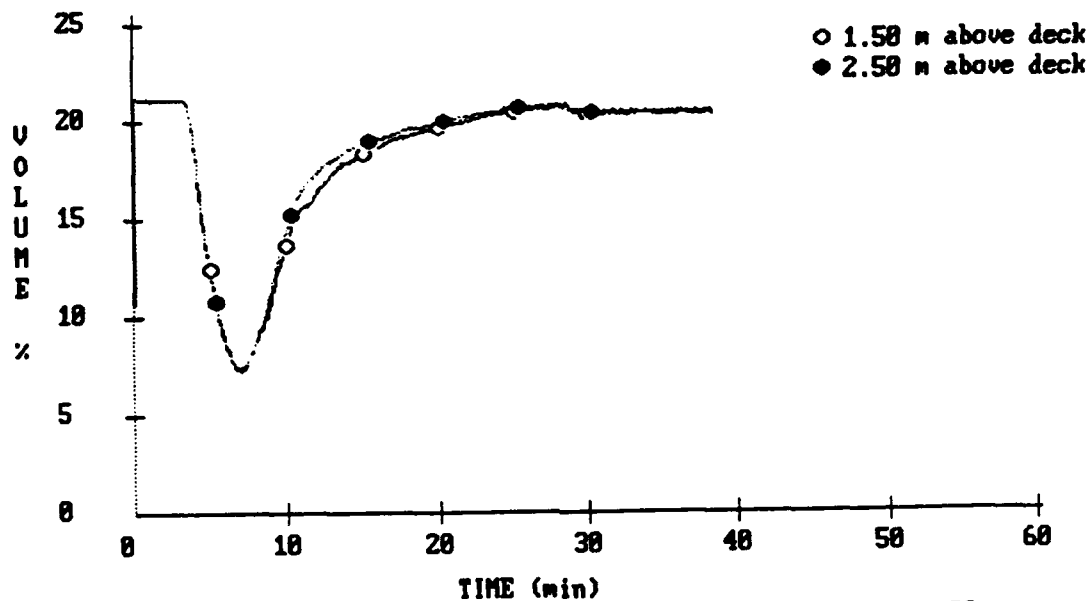


Fig. B-177- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 22

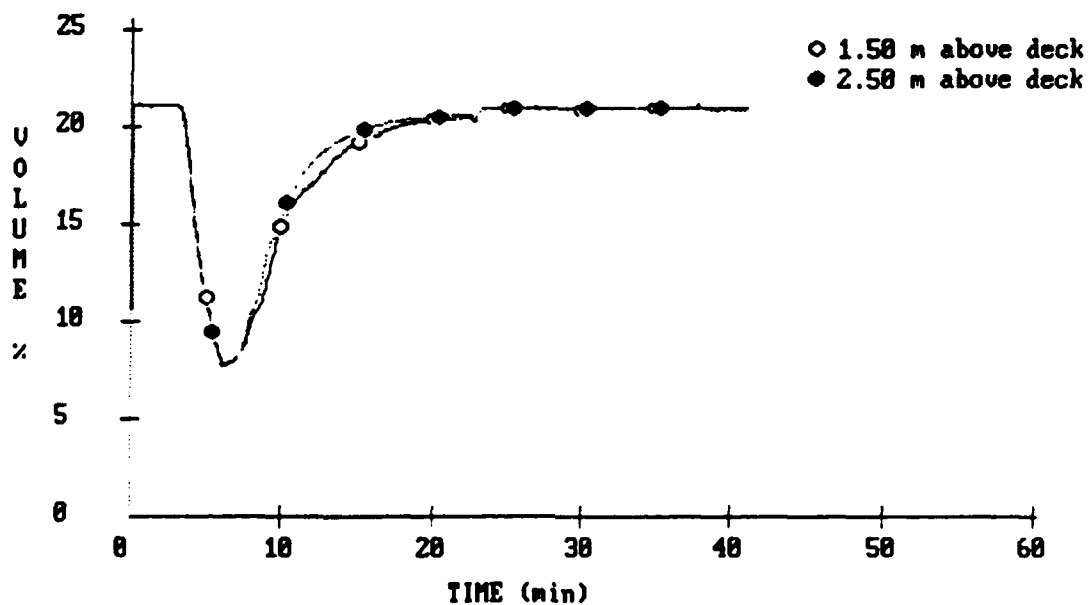


Fig. B-178- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 23

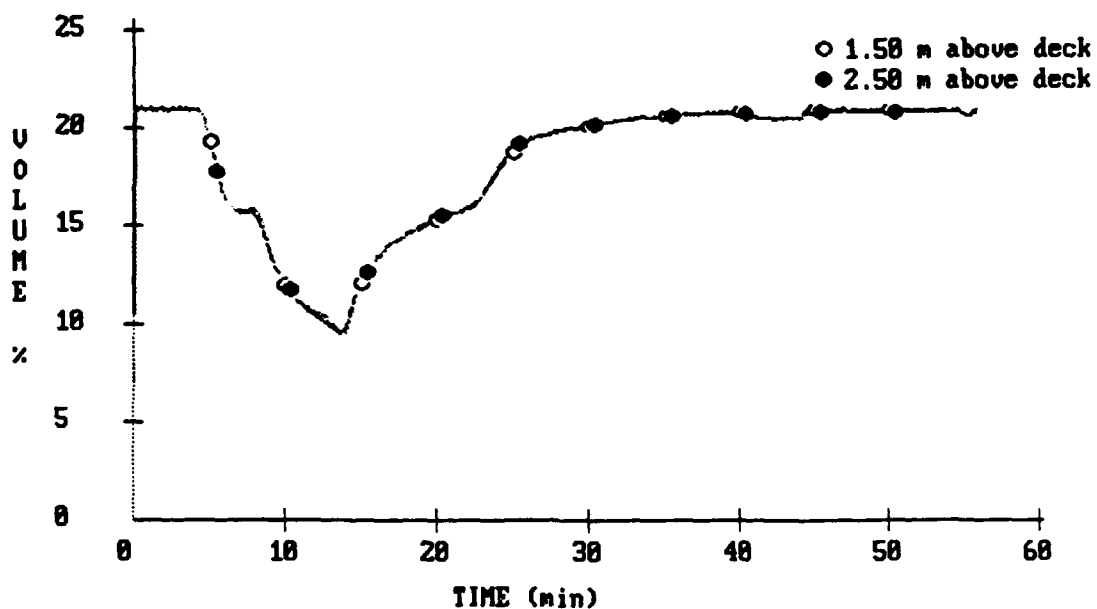


Fig. B-179- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 24

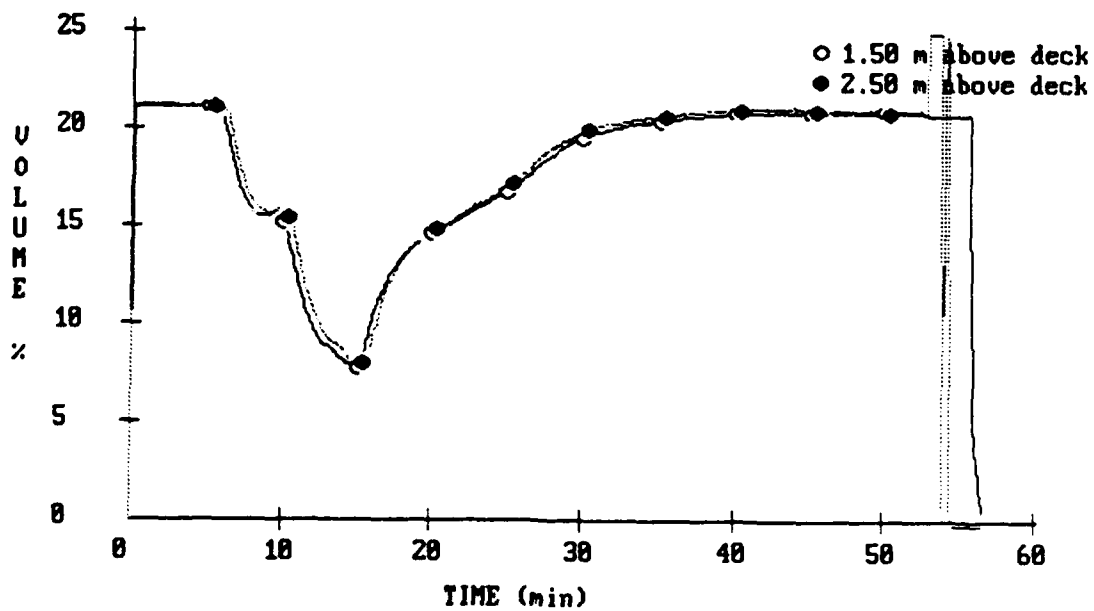


Fig. B-180- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 25

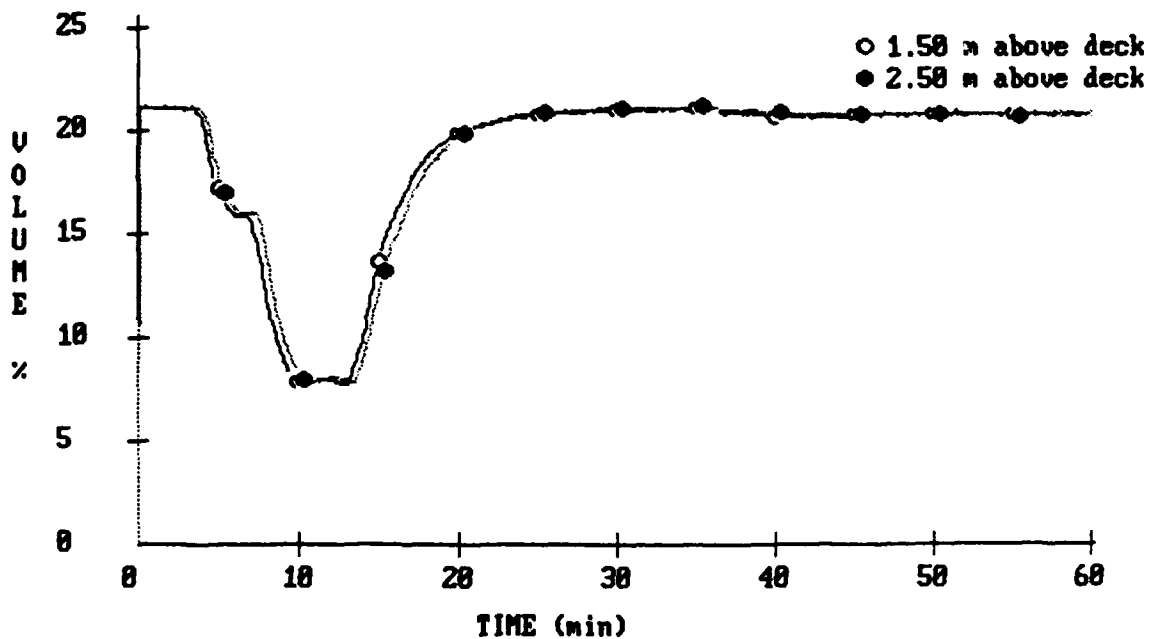


Fig. B-181- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 26

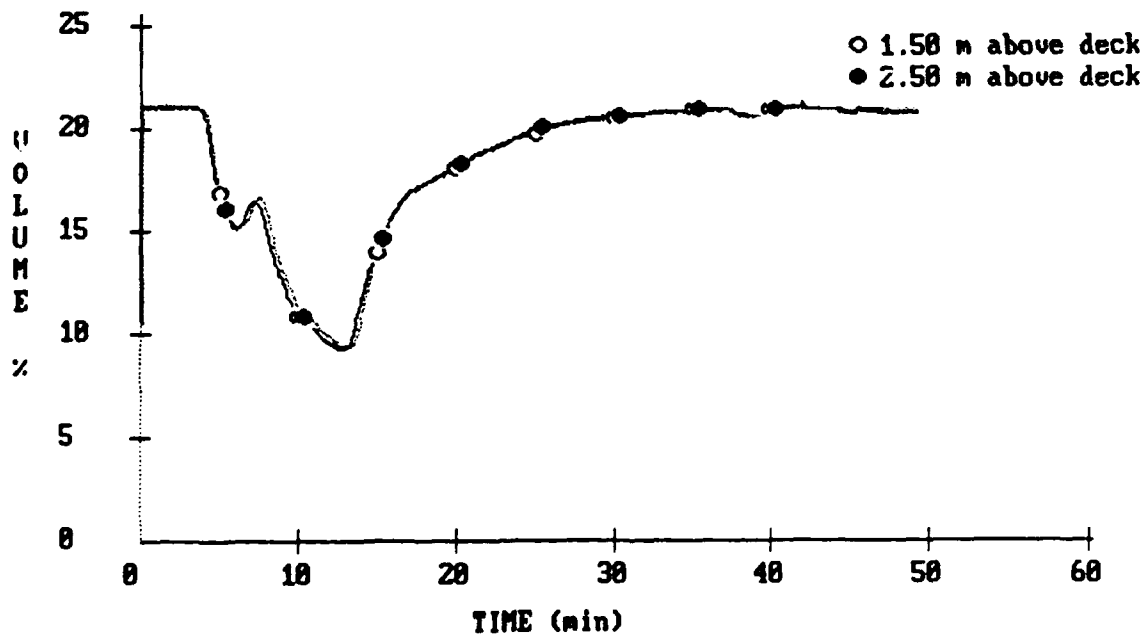


Fig. B-182- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 27

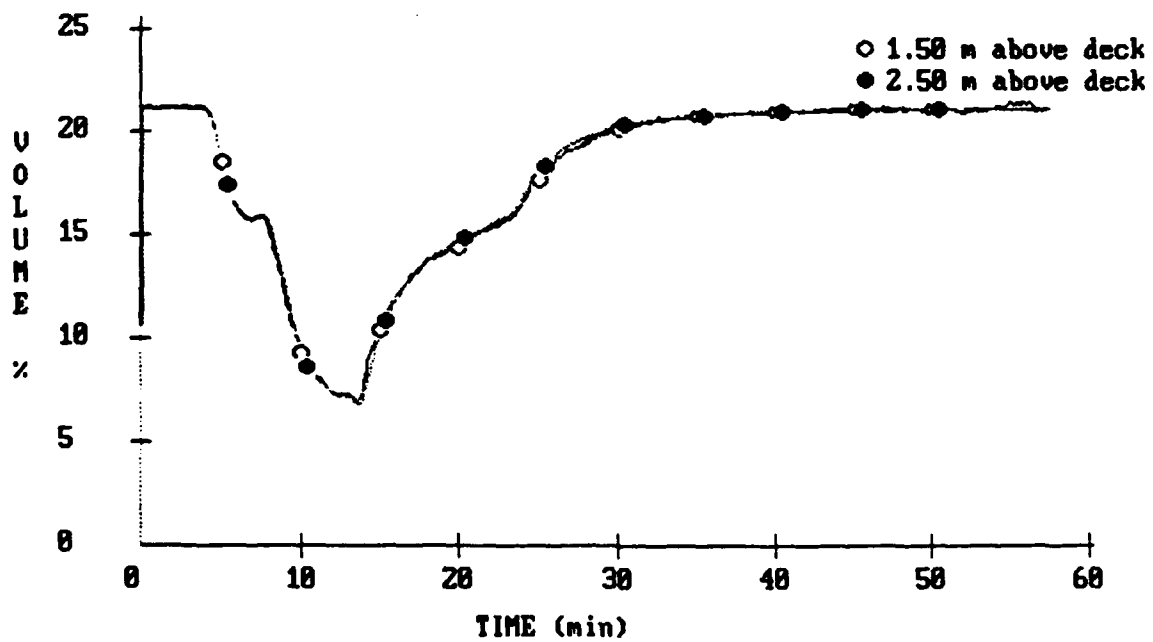


Fig. B-183- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 28

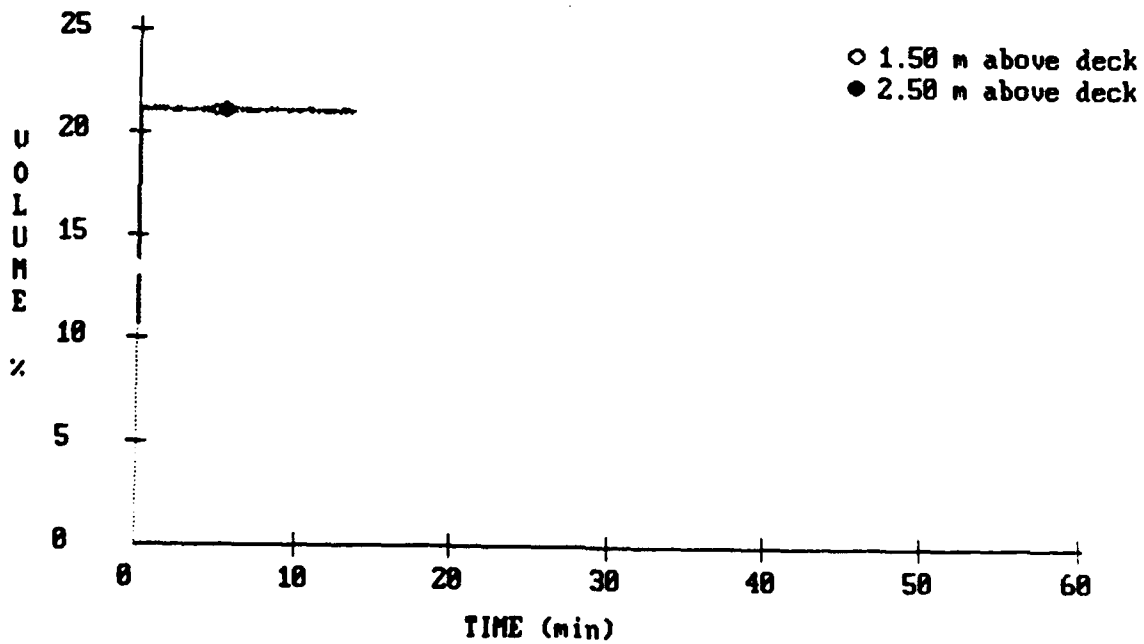


Fig. B-184- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 29



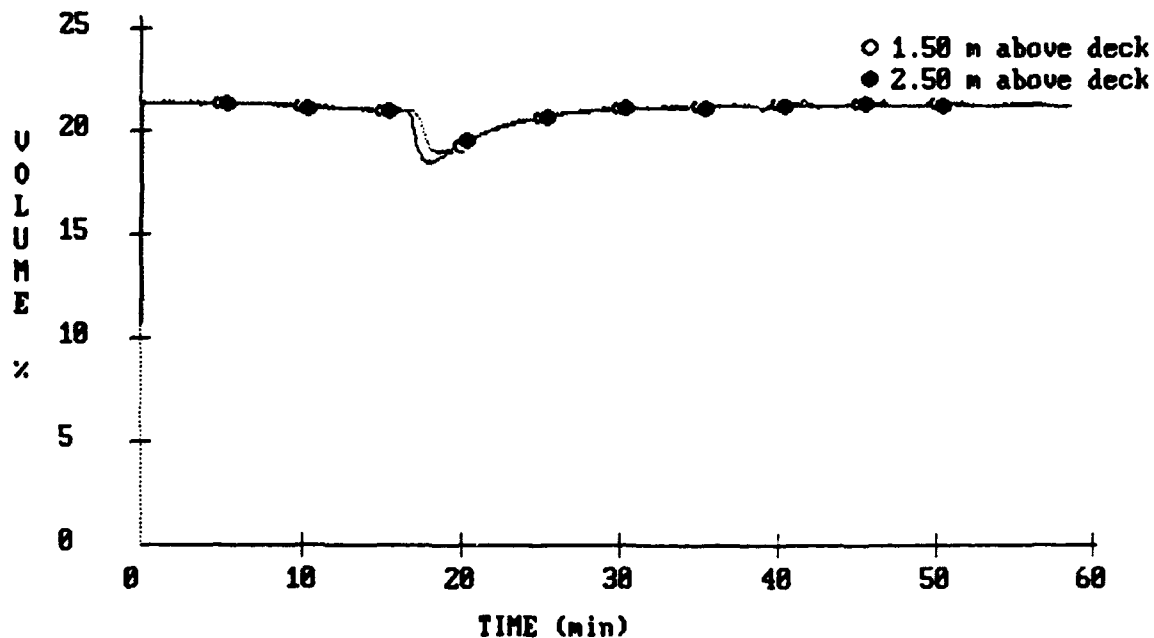


Fig. B-185- O2 concentration in BERTHING 1 (3-76-2) during Test # 30

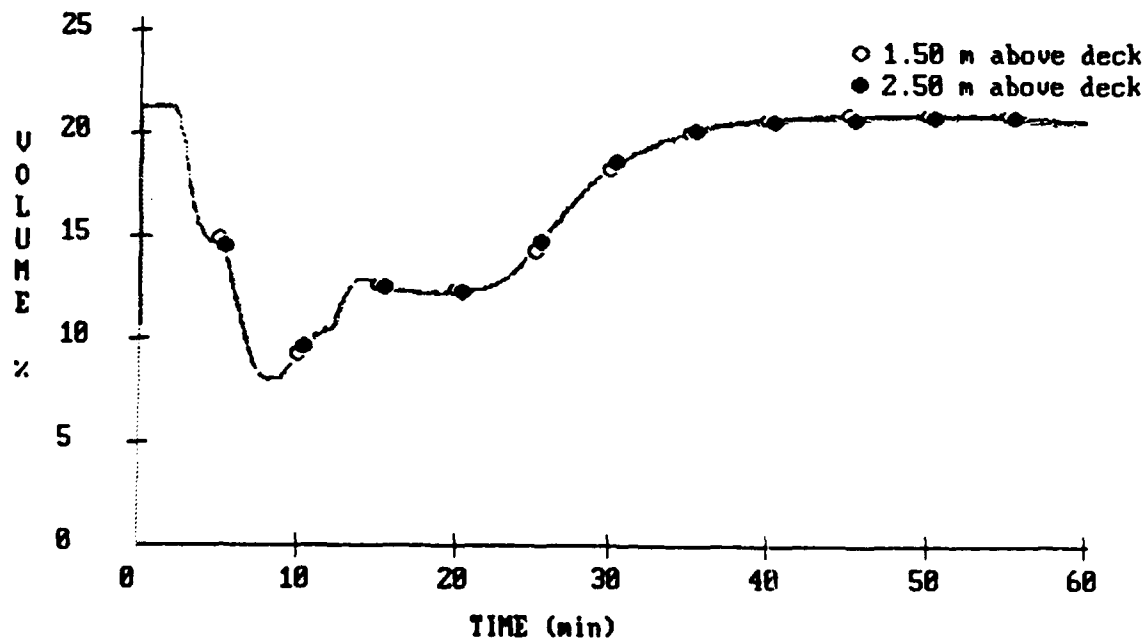


Fig. B-186- O2 concentration in BERTHING 1 (3-76-2) during Test # 31

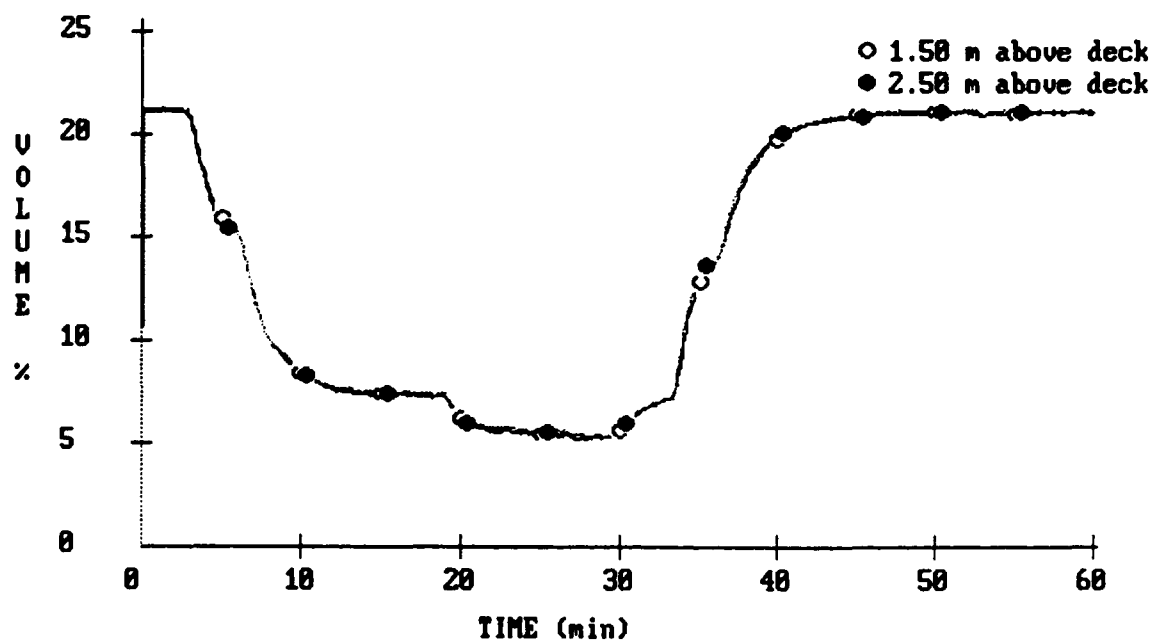


Fig. B-187- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 32

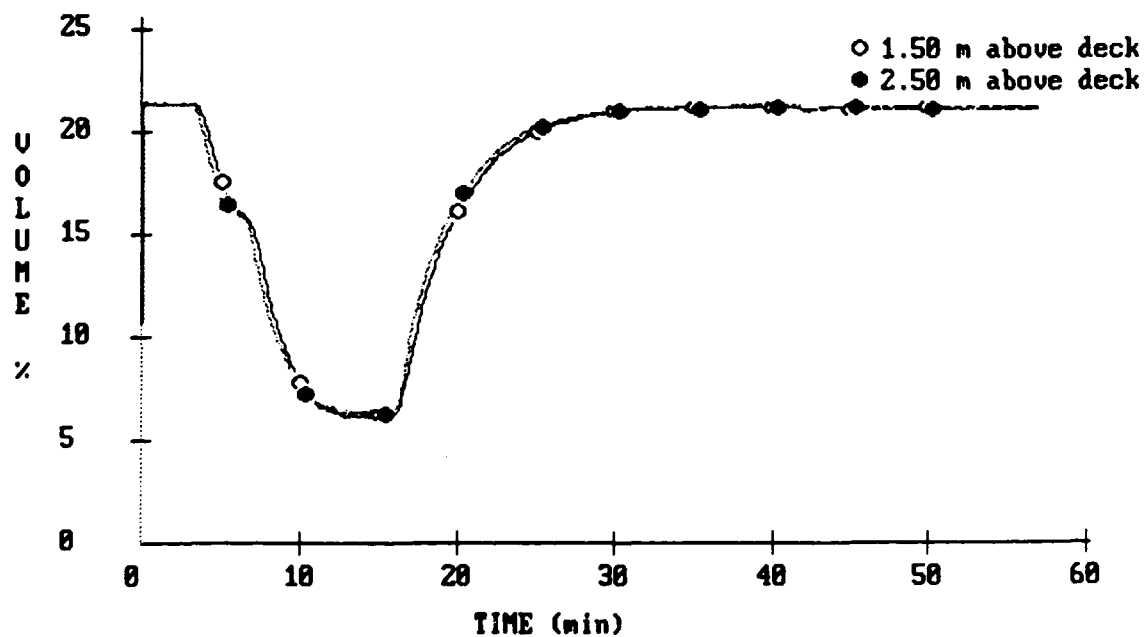


Fig. B-188- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 33

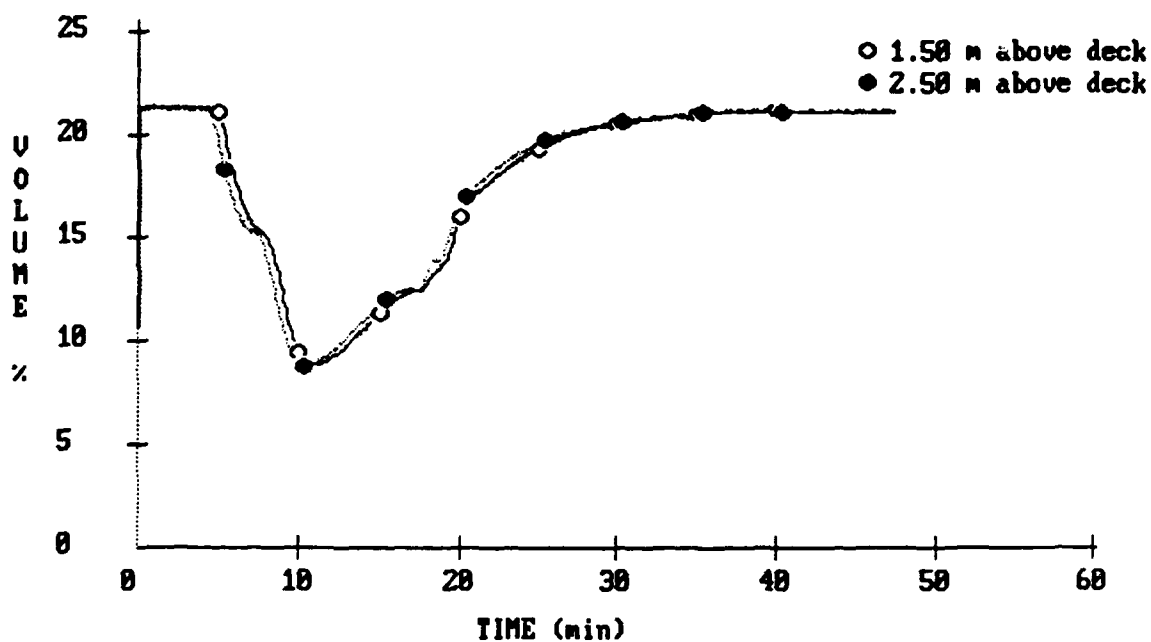


Fig. B-189- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 34

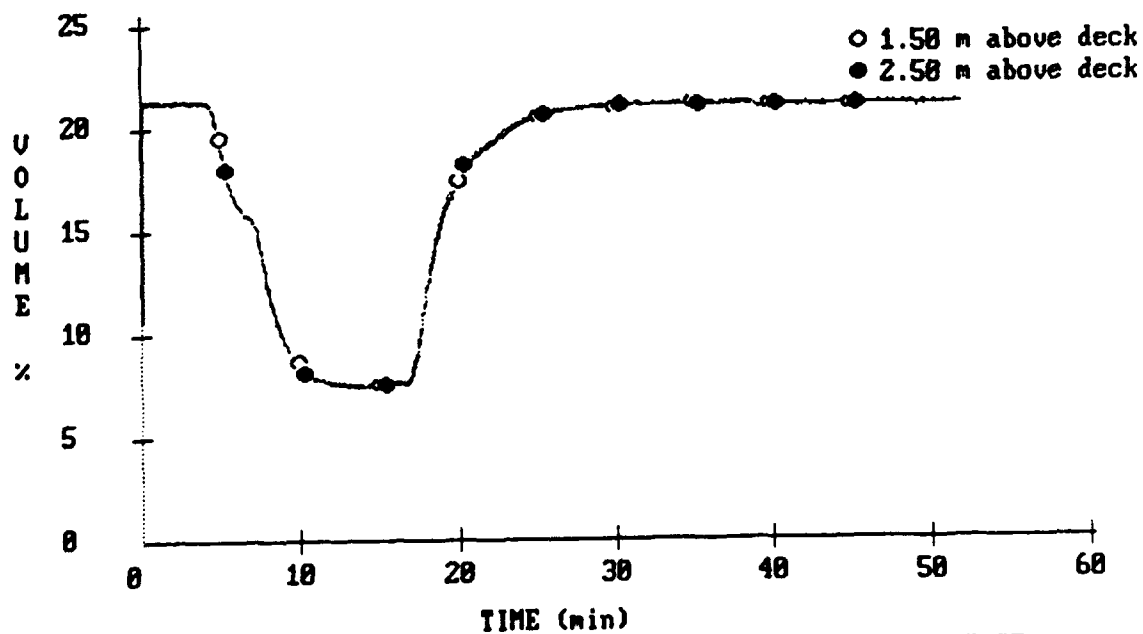


Fig. B-190- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 35

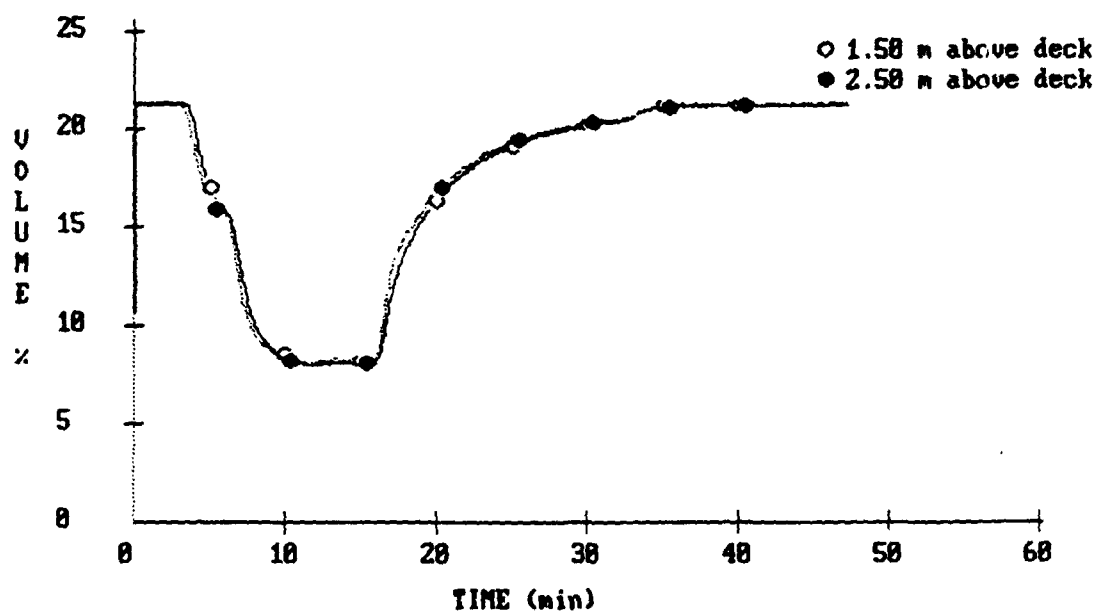


Fig. B-191- O2 concentration in BERTHING 1 (3-76-2) during Test # 36

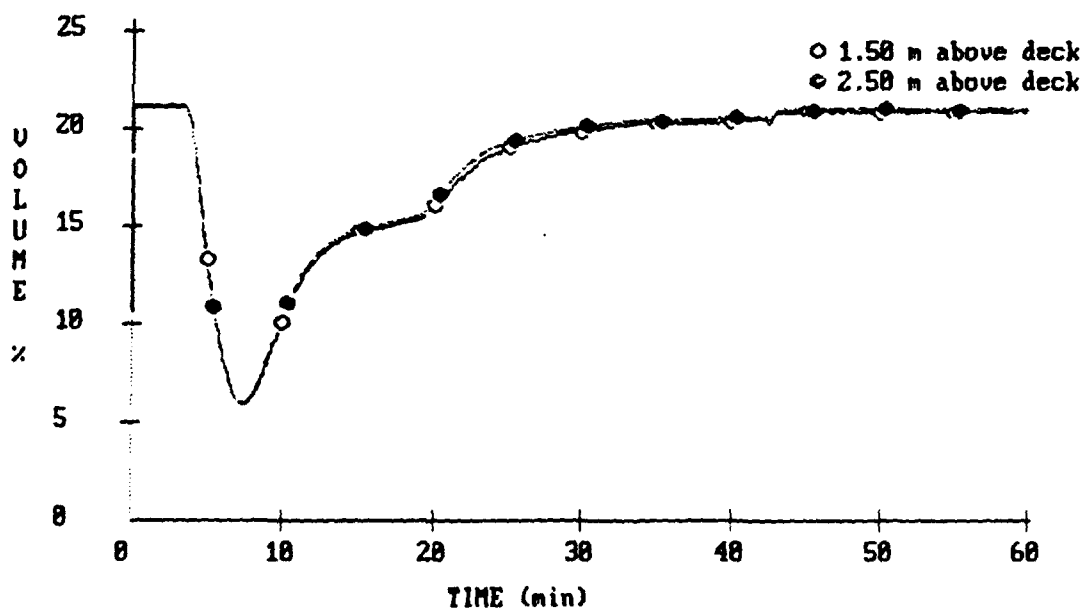


Fig. B-192- O2 concentration in BERTHING 1 (3-76-2) during Test # 37

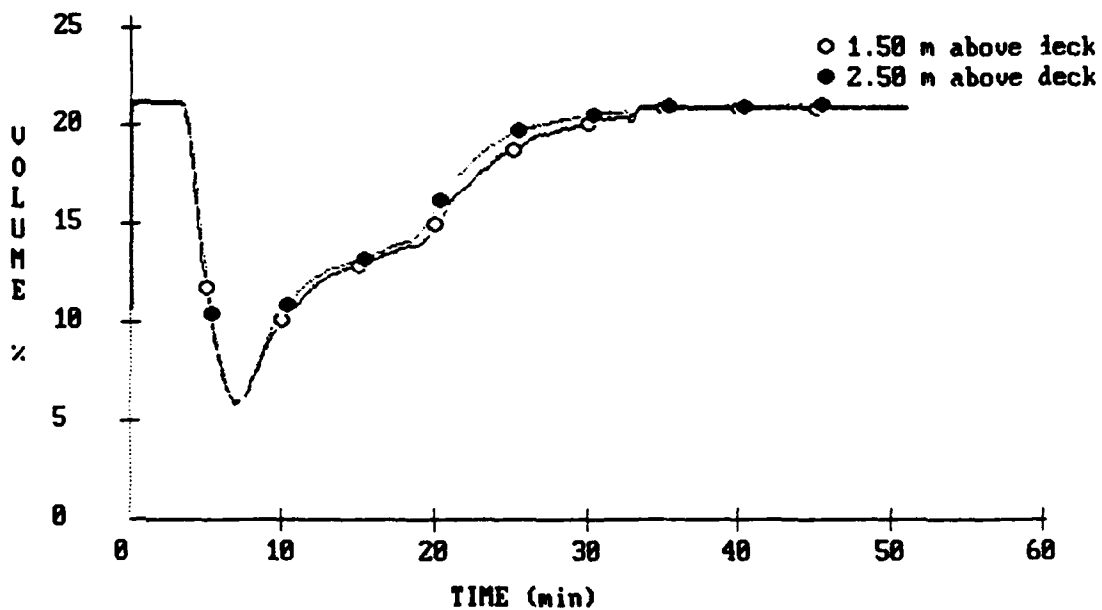


Fig. B-193- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 38

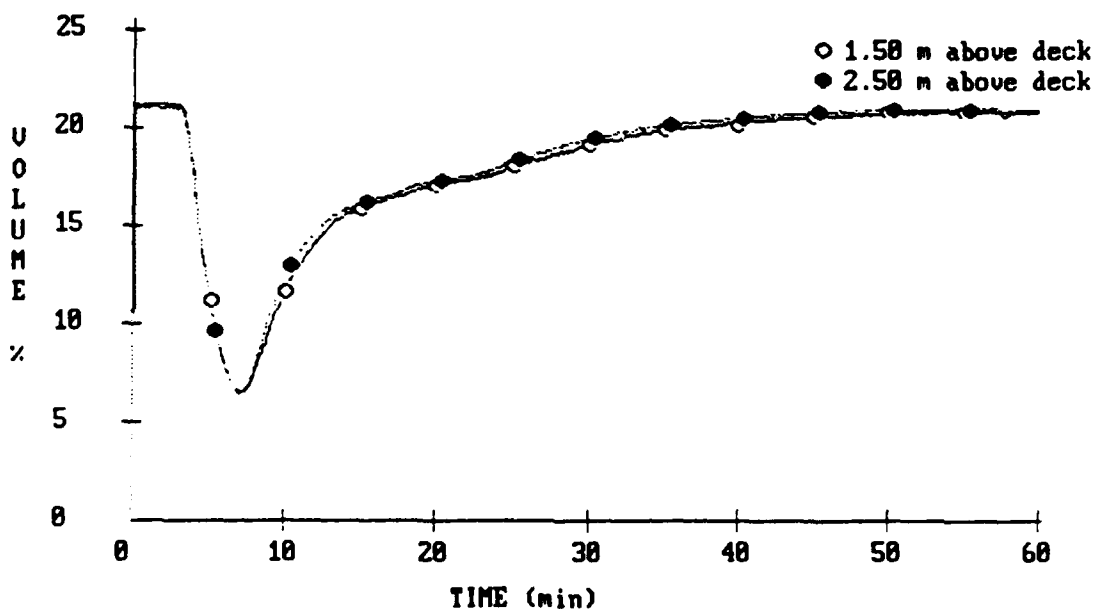


Fig. B-194- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 39

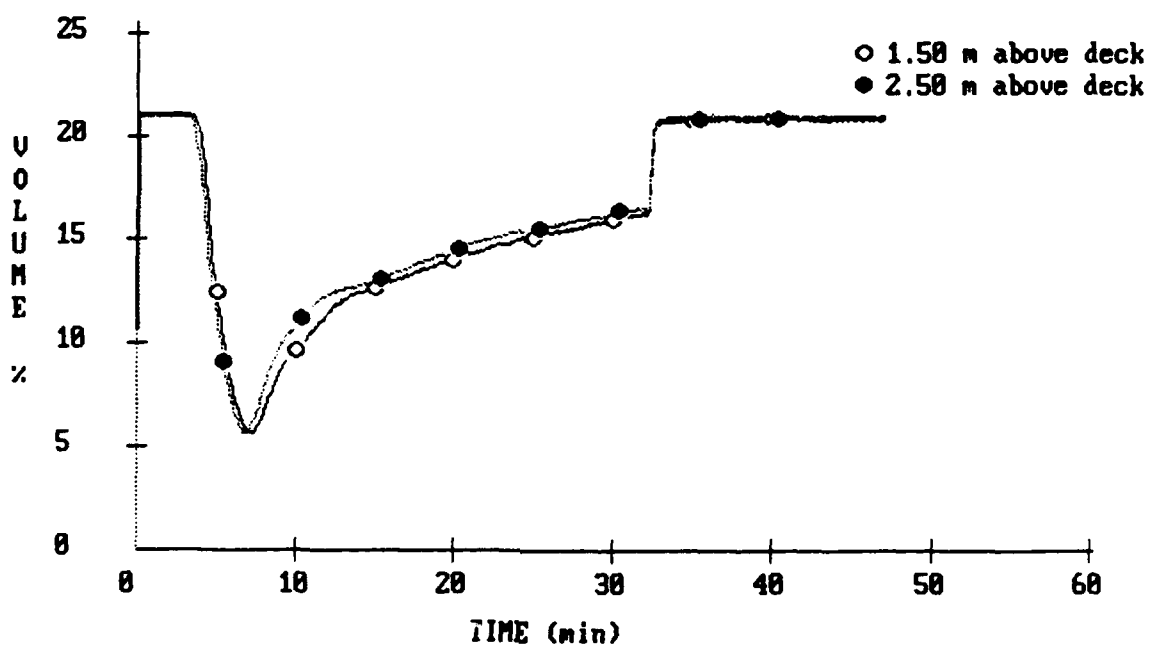


Fig. B-195- O<sub>2</sub> concentration in BERTHING 1 (3-76-2) during Test # 40

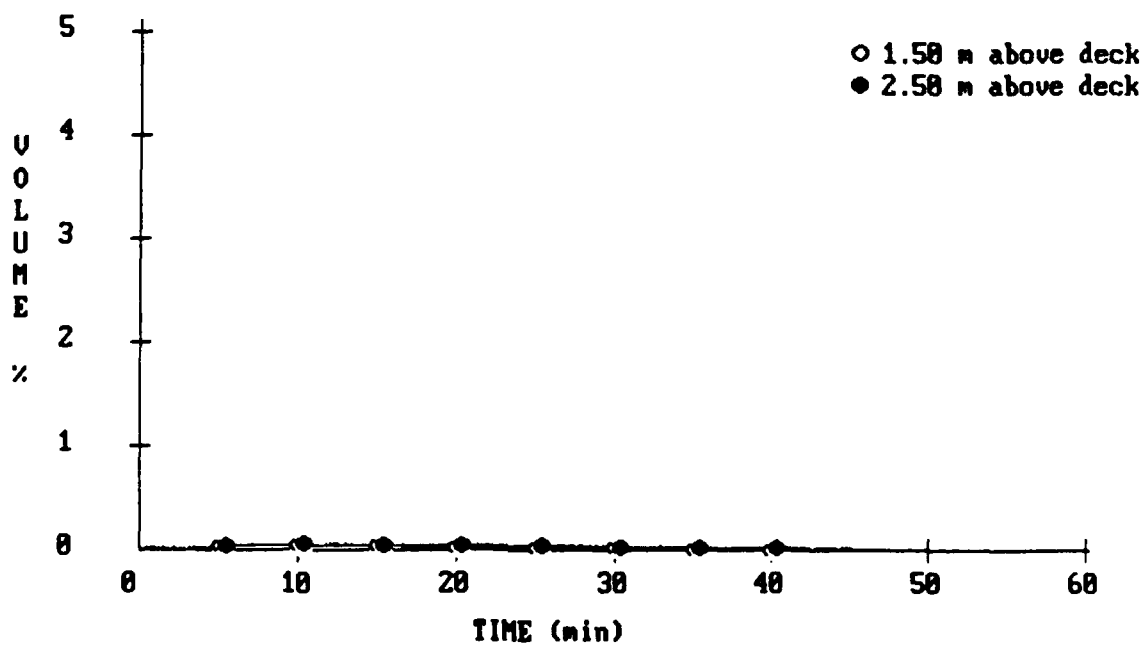


Fig. B-196- CO concentration in RICER 1 (2-76-2) during Test # 2

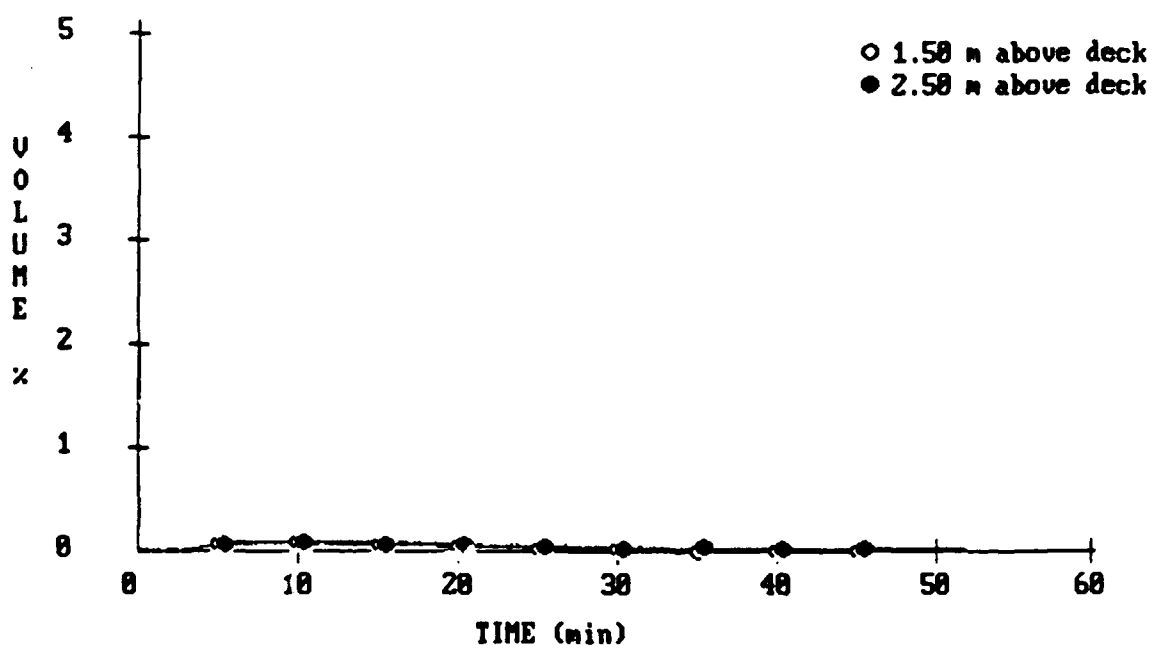


Fig. B-197- CO concentration in RICER 1 (2-76-2) during Test # 3

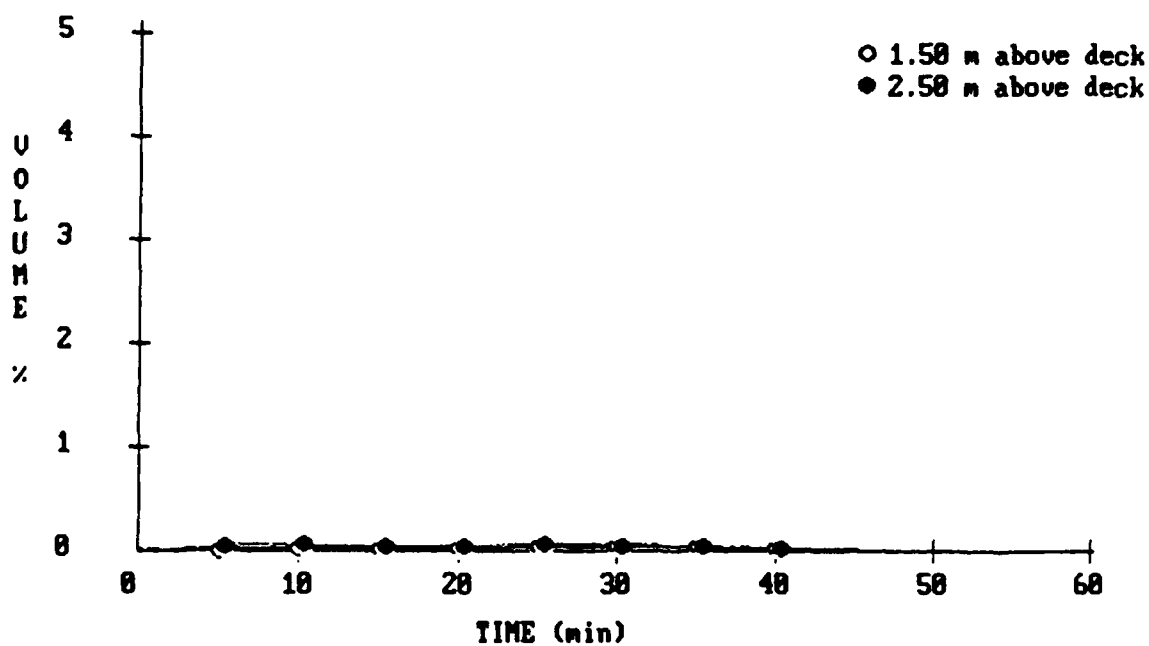


Fig. B-198- CO concentration in RICER 1 (2-76-2) during Test # 4

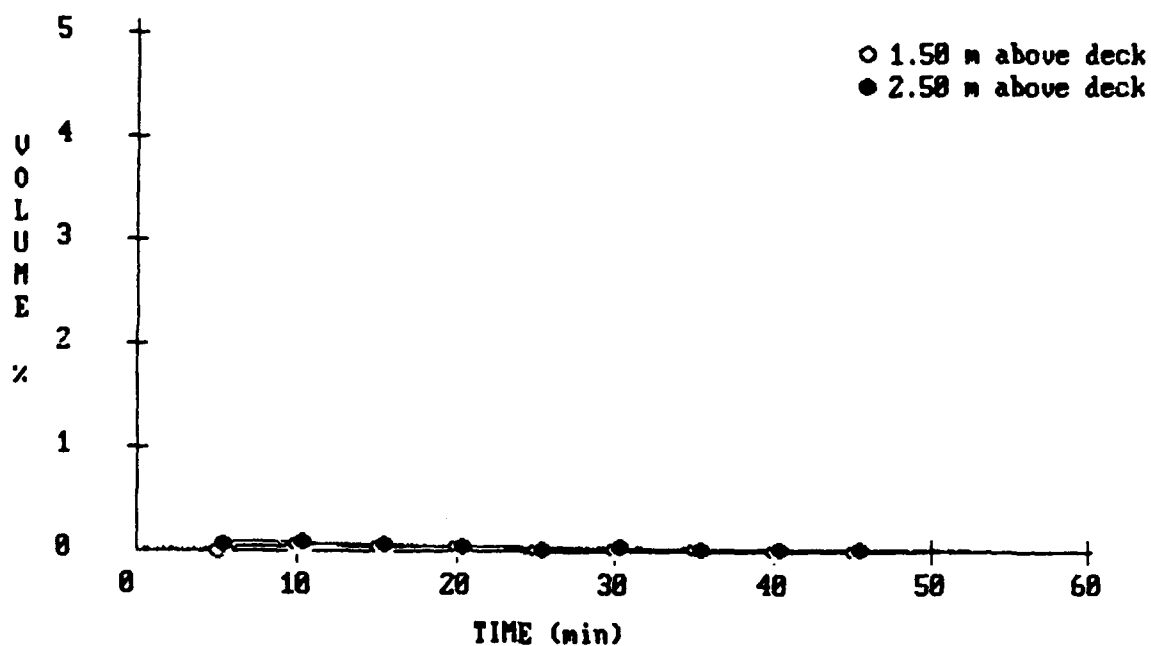


Fig. B-199- CO concentration in RICER 1 (2-76-2) during Test # 5

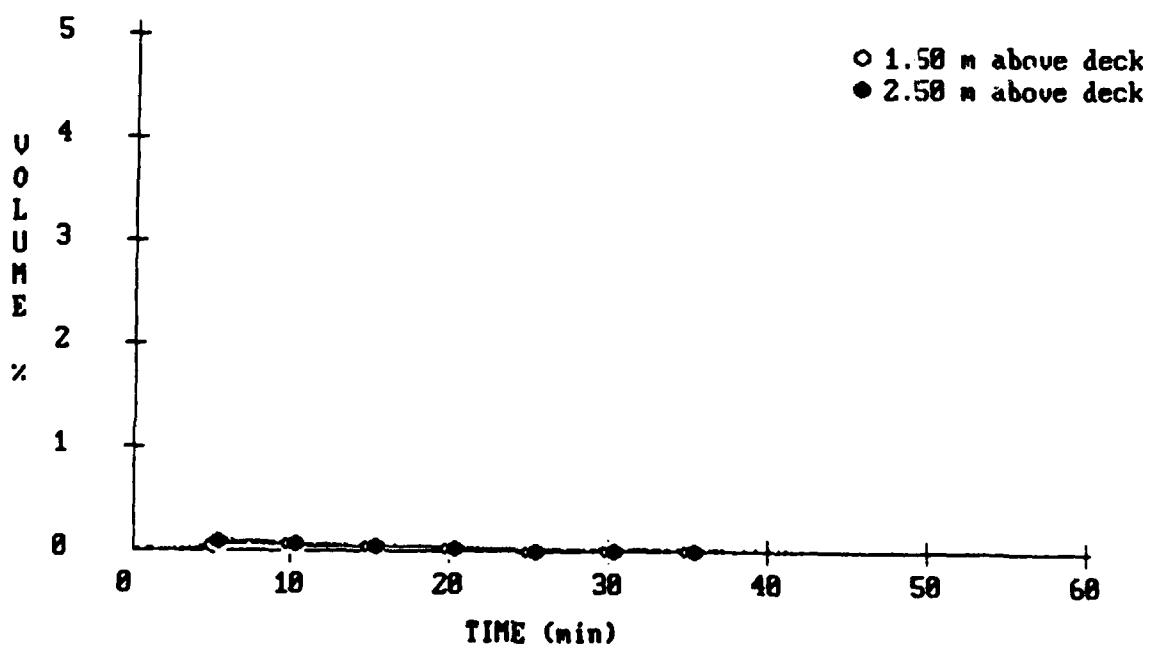


Fig. B-200- CO concentration in RICER 1 (2-76-2) during Test # 6



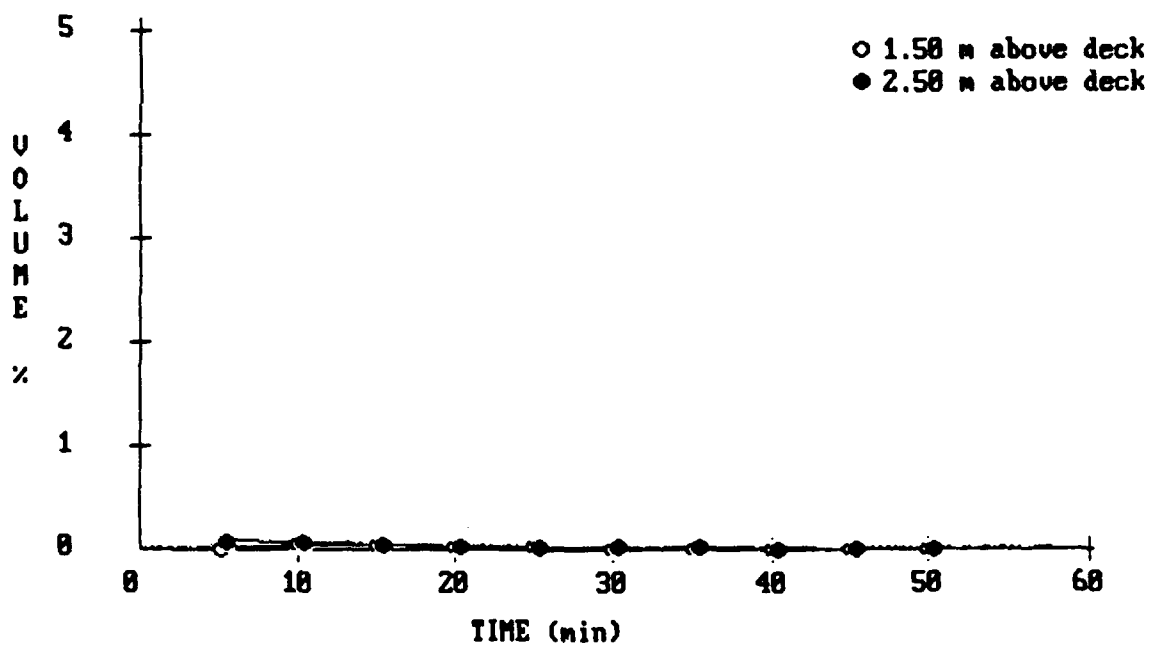


Fig. B-201- CO concentration in RICER 1 (2-76-2) during Test # 7

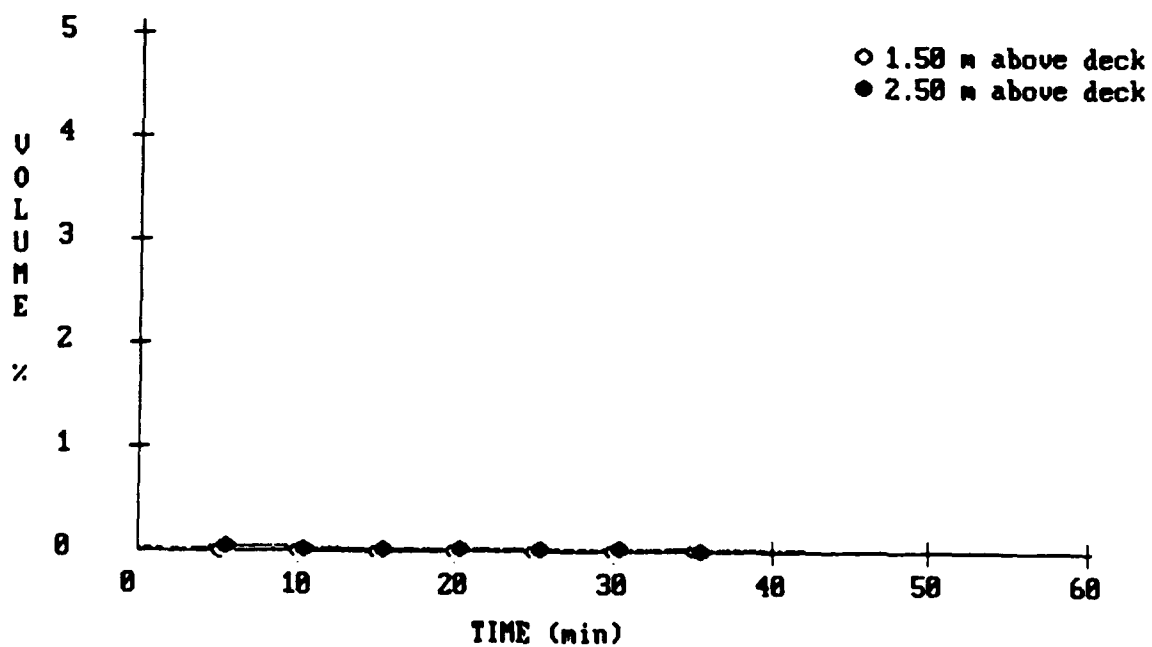


Fig. B-202- CO concentration in RICER 1 (2-76-2) during Test # 8

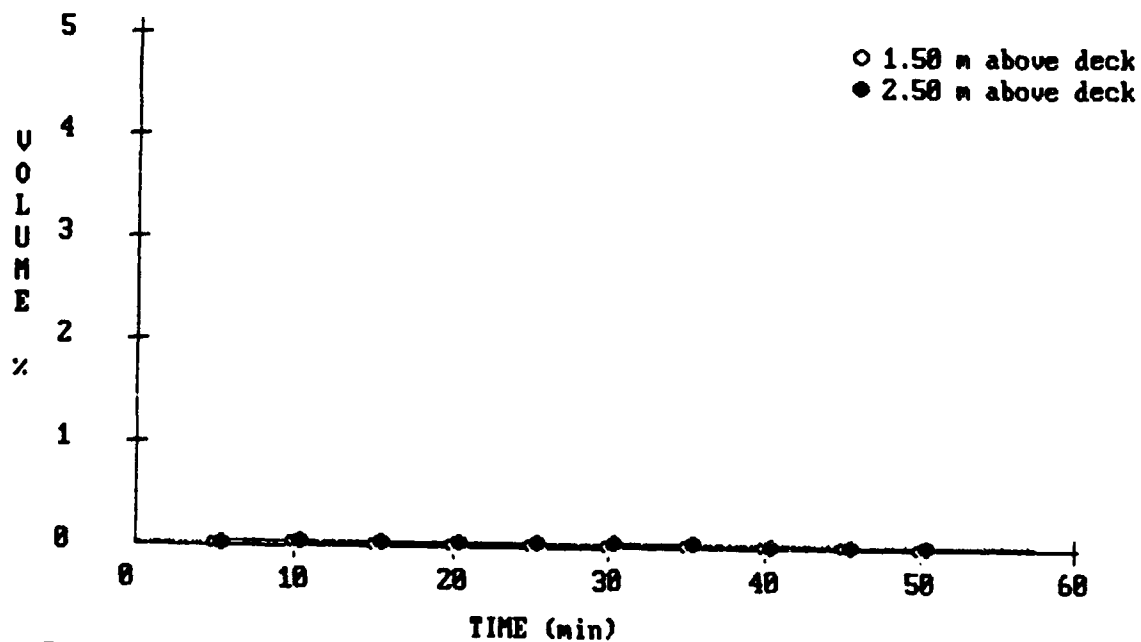


Fig. B-203- CO concentration in RICER 1 (2-76-2) during Test # 9

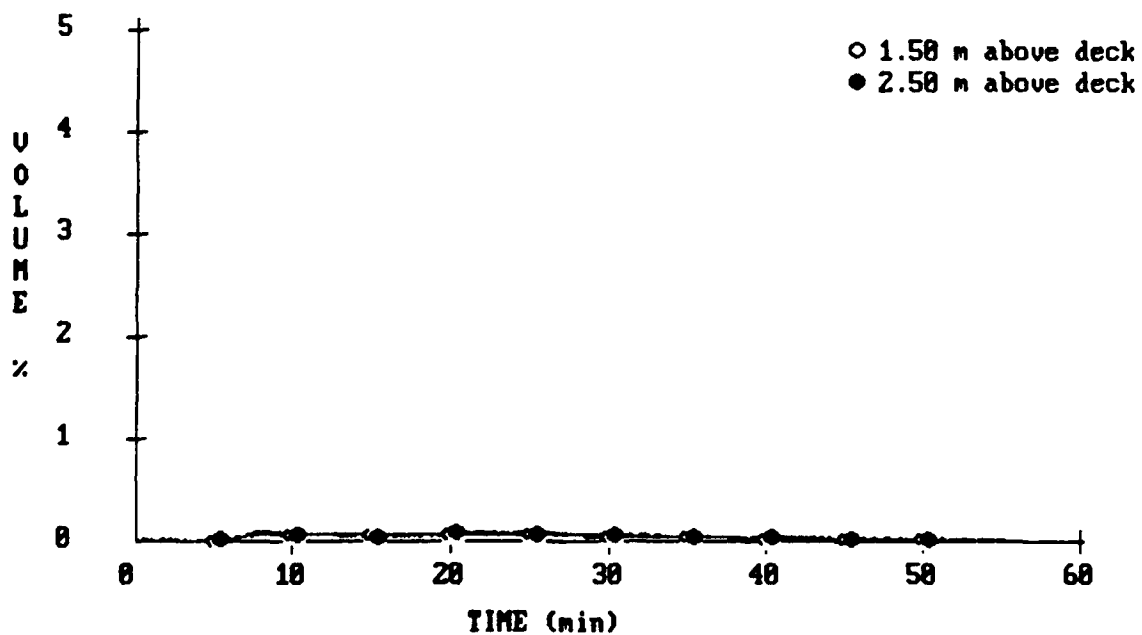


Fig. B-204- CO concentration in RICER 1 (2-76-2) during Test # 10

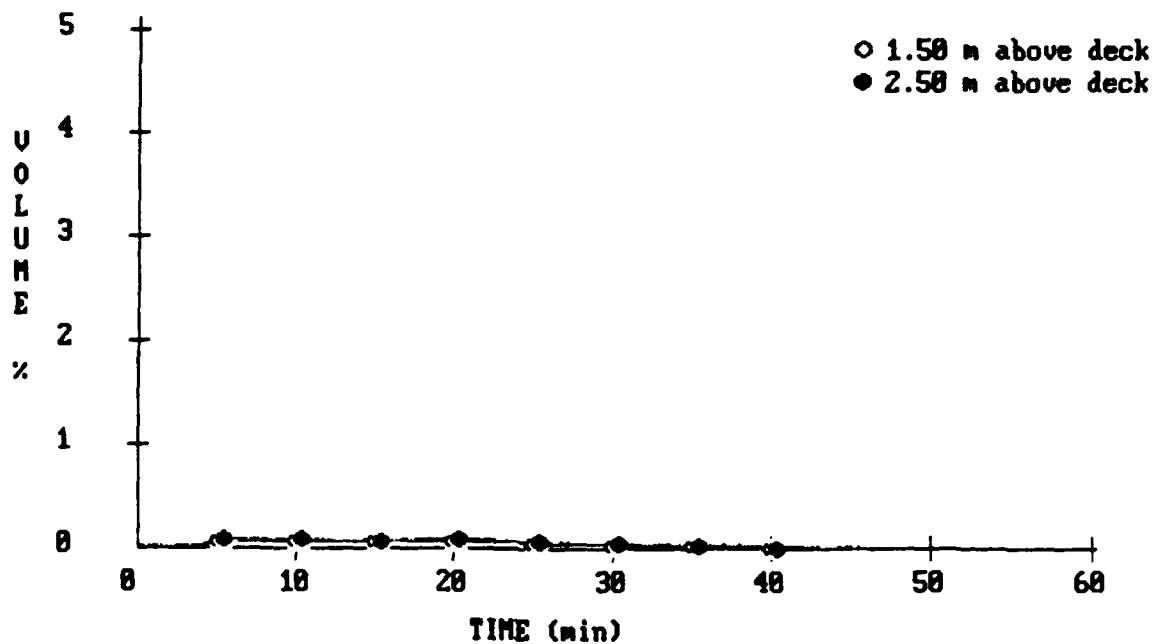


Fig. B-205- CO concentration in RICER 1 (2-76-2) during Test # 11

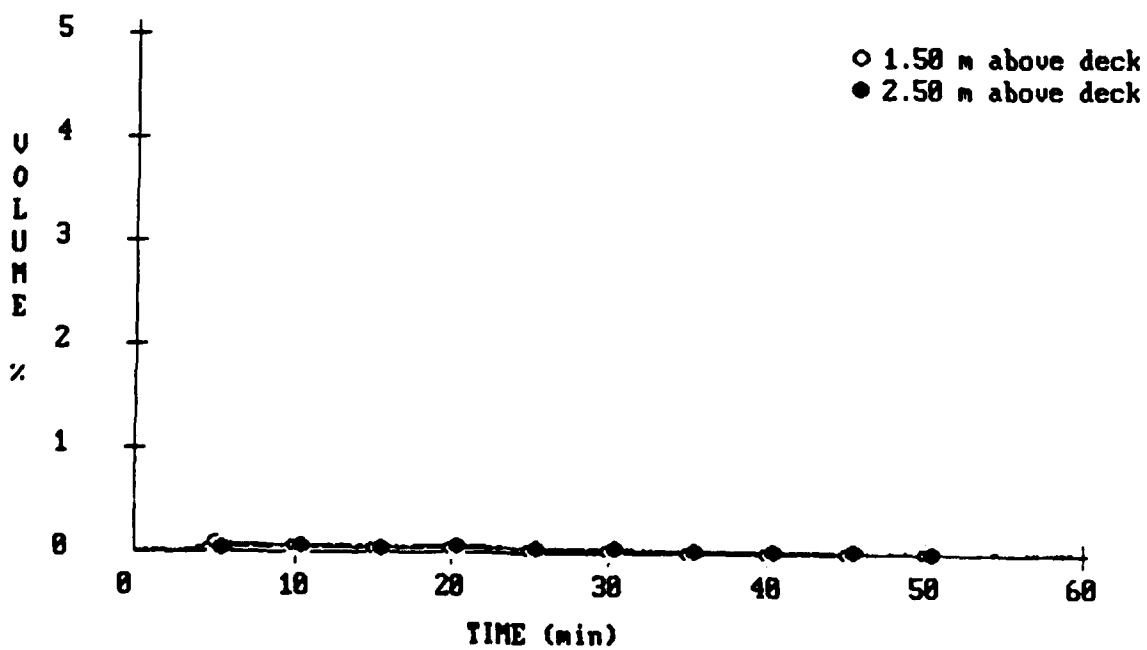


Fig. B-206- CO concentration in RICER 1 (2-76-2) during Test # 12

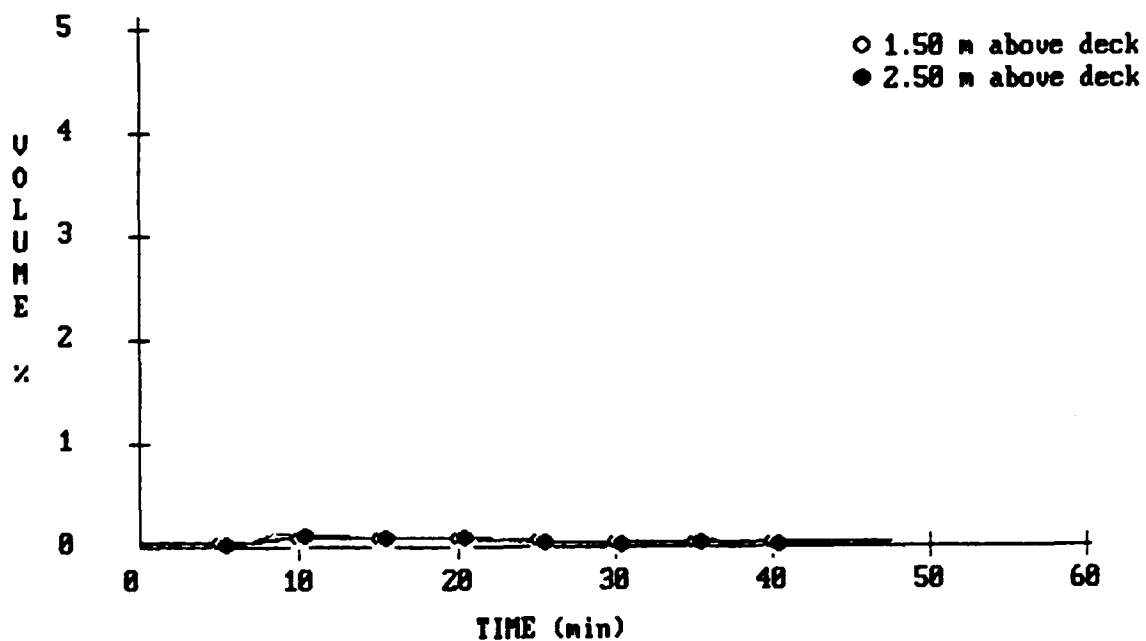


Fig. B-207- CO concentration in RICER 1 (2-76-2) during Test # 13

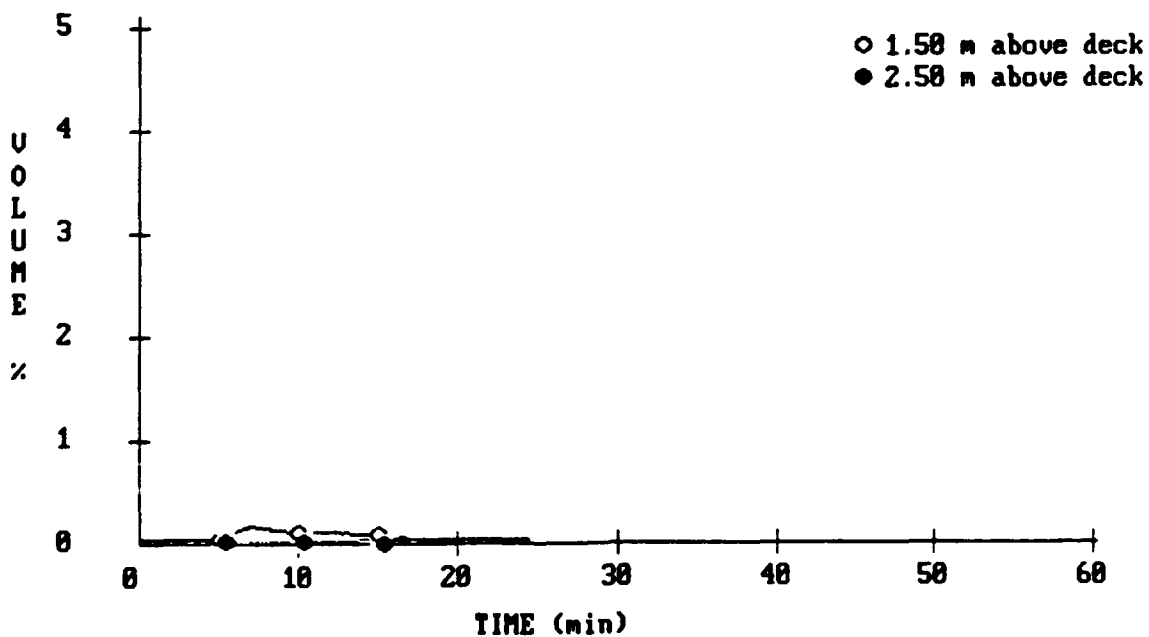


Fig. B-208- CO concentration in RICER 1 (2-76-2) during Test # 14

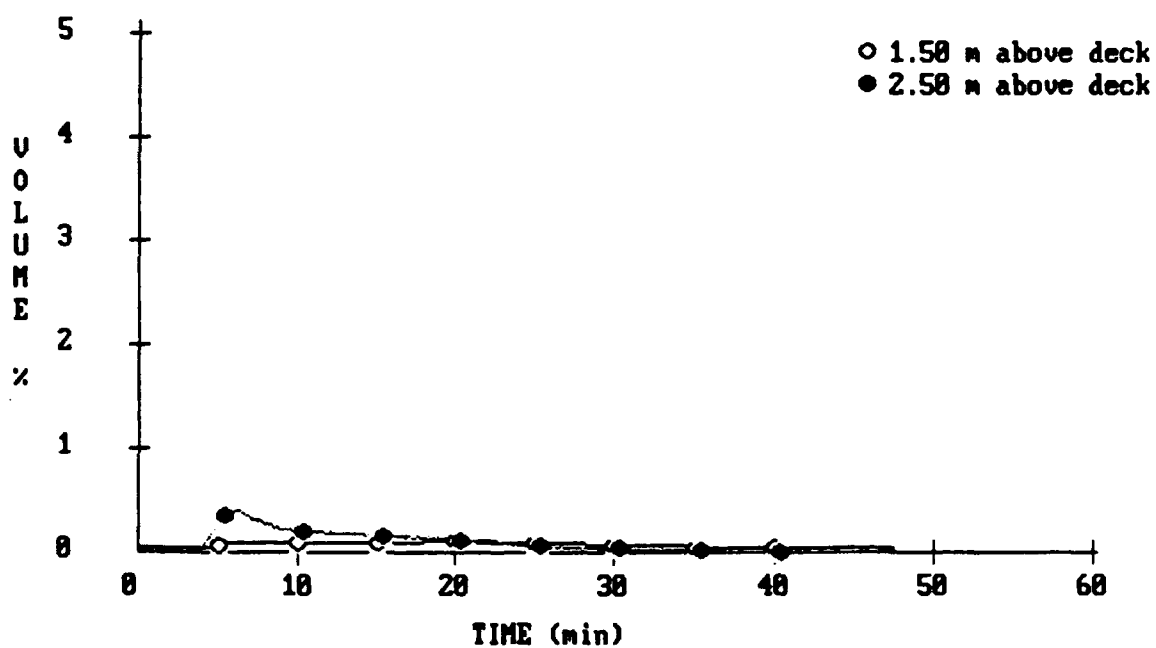


Fig. B-209- CO concentration in RICER 1 (2-76-2) during Test # 15

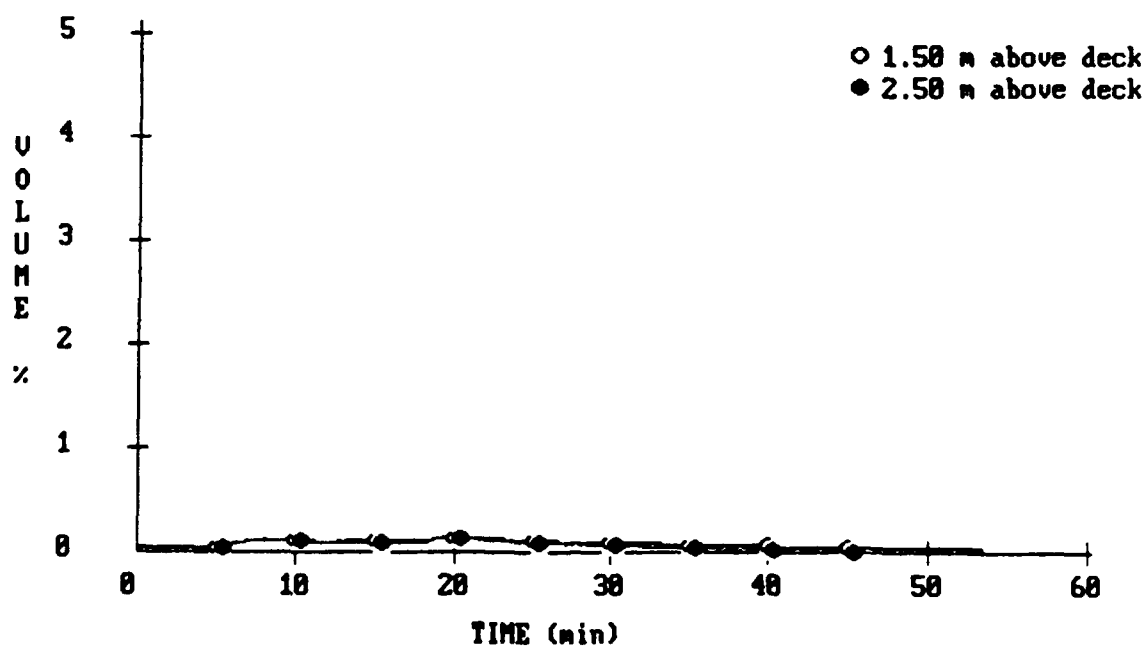


Fig. B-210- CO concentration in RICER 1 (2-76-2) during Test # 16

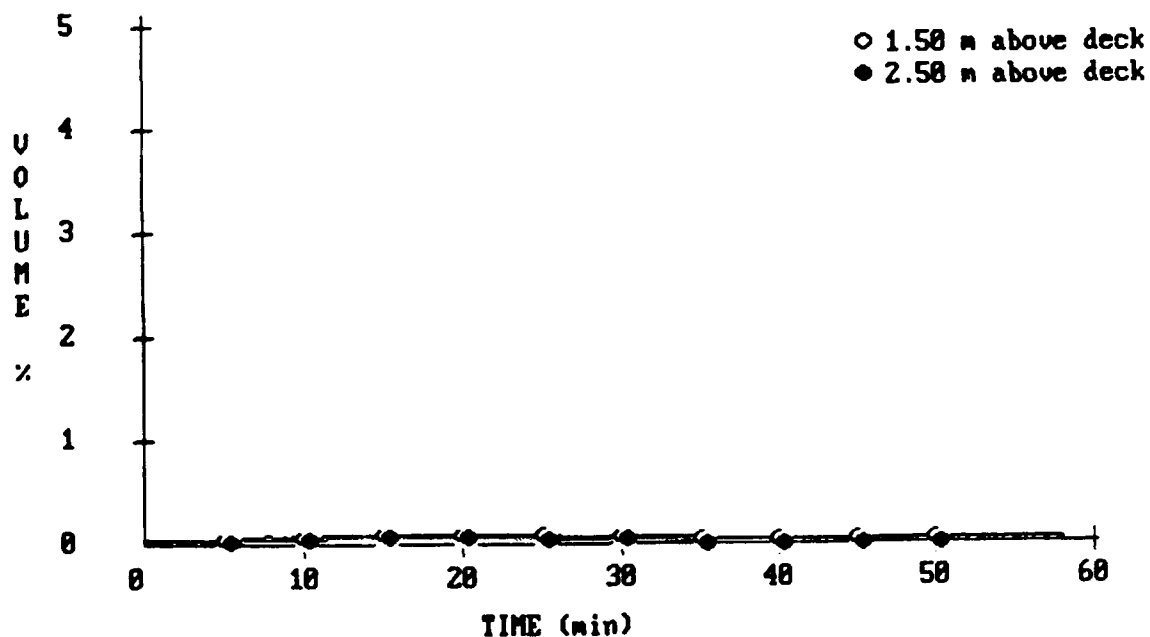


Fig. B-211- CO concentration in RICER 1 (2-76-2) during Test # 17

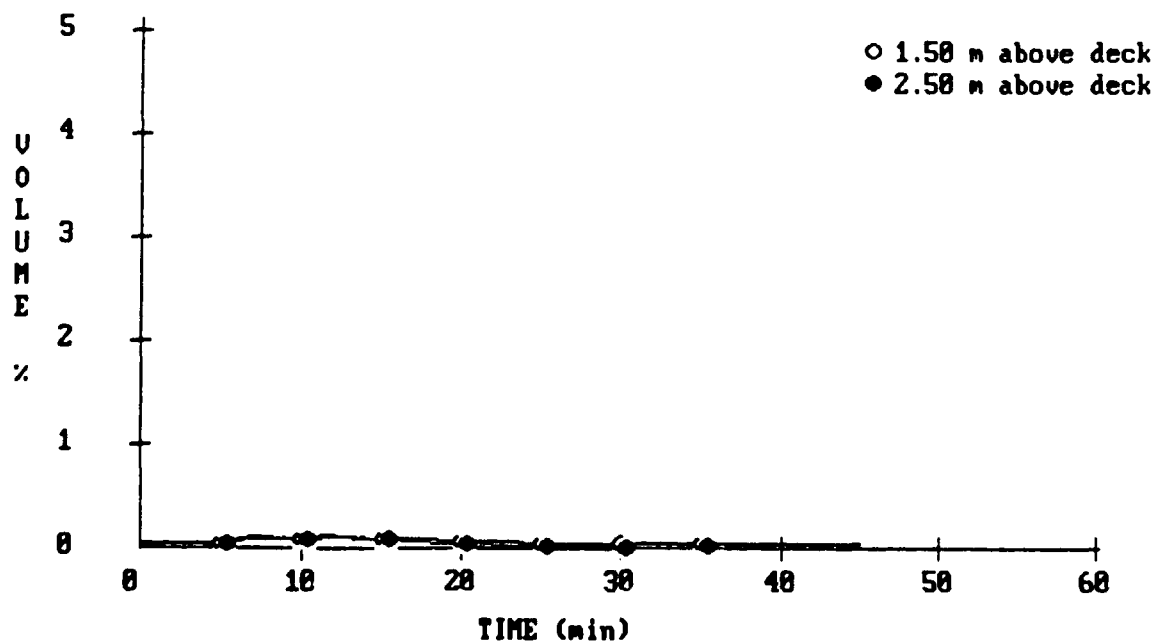


Fig. B-212- CO concentration in RICER 1 (2-76-2) during Test # 18

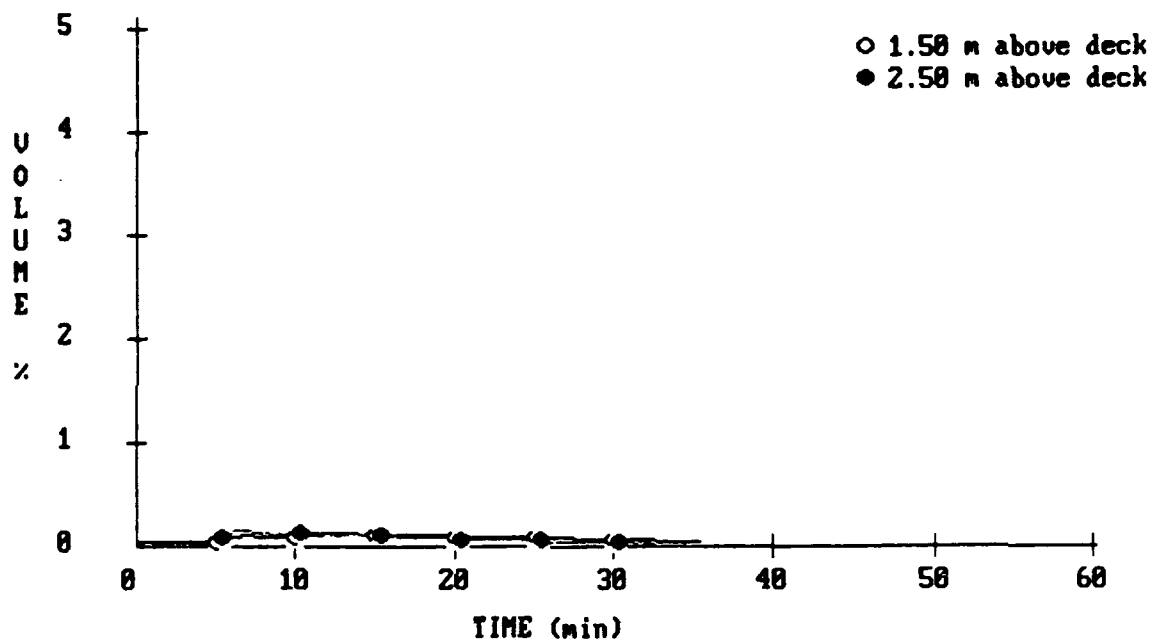


Fig. B-213- CO concentration in RICER 1 (2-76-2) during Test # 19

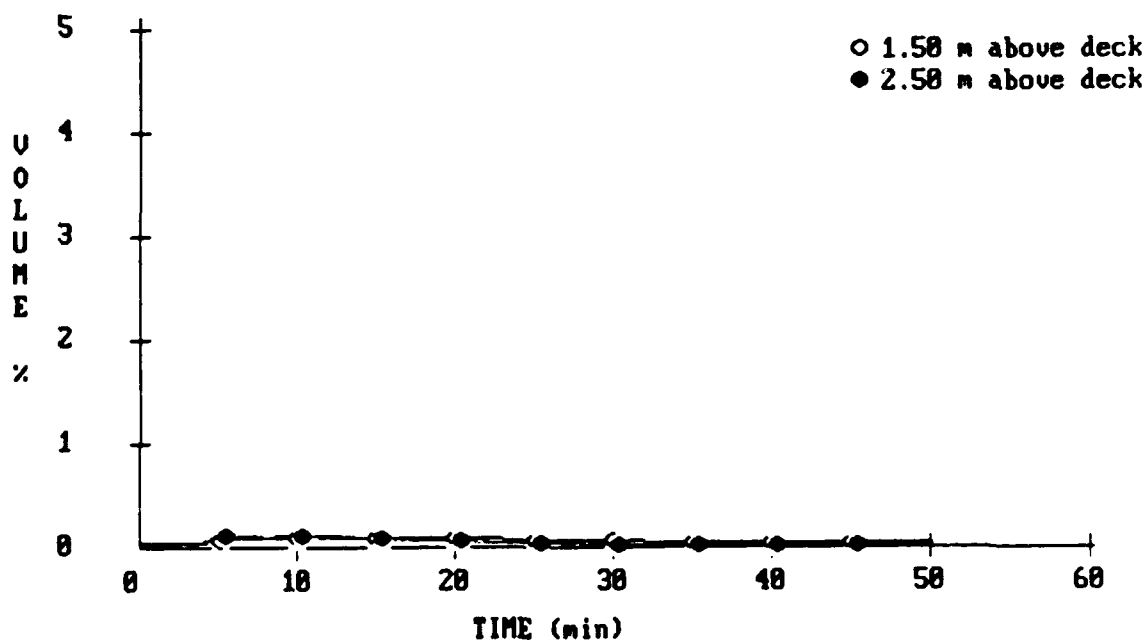


Fig. B-214- CO concentration in RICER 1 (2-76-2) during Test # 20

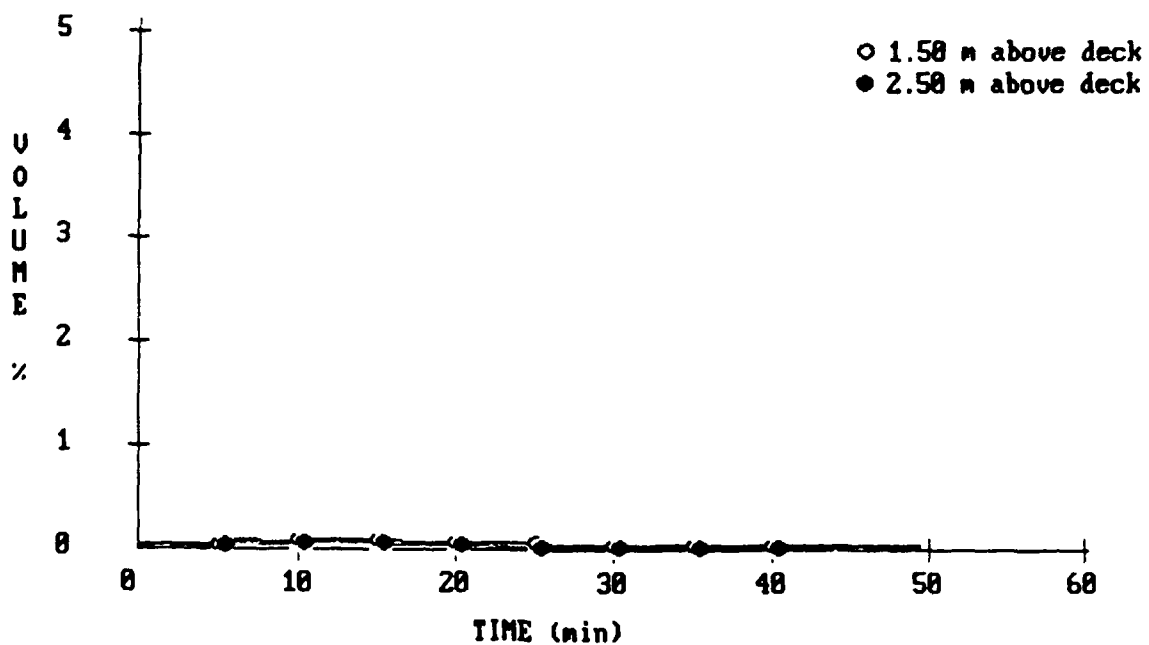


Fig. B-215- CO concentration in RICER 1 (2-76-2) during Test # 21

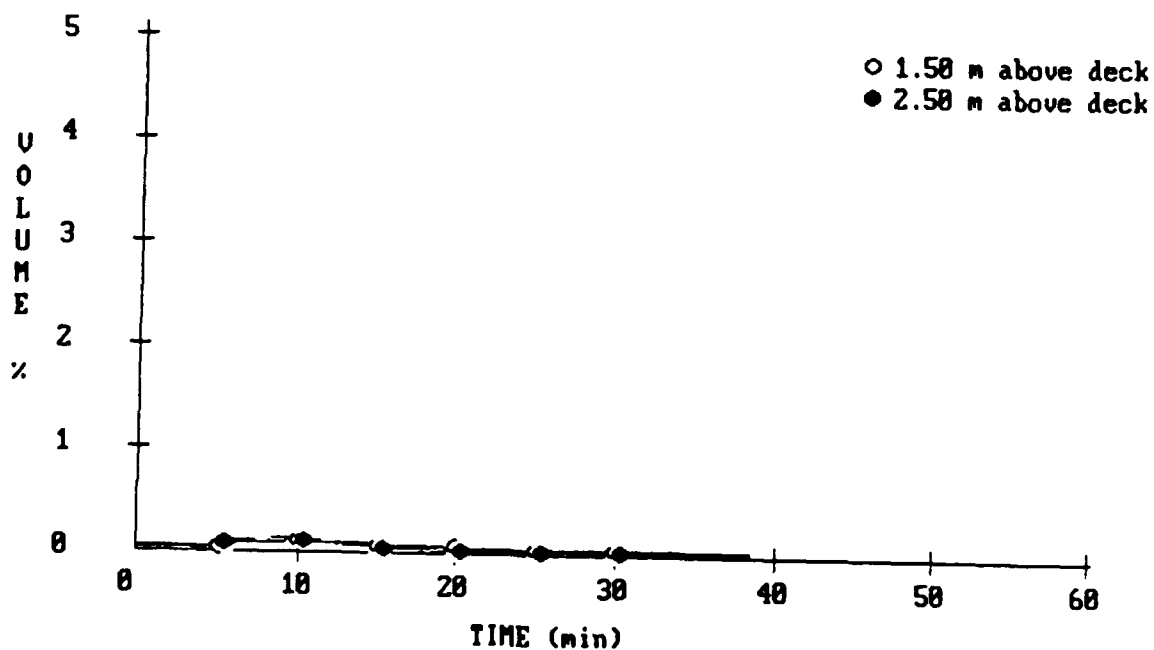


Fig. B-216- CO concentration in RICER 1 (2-76-2) during Test # 22



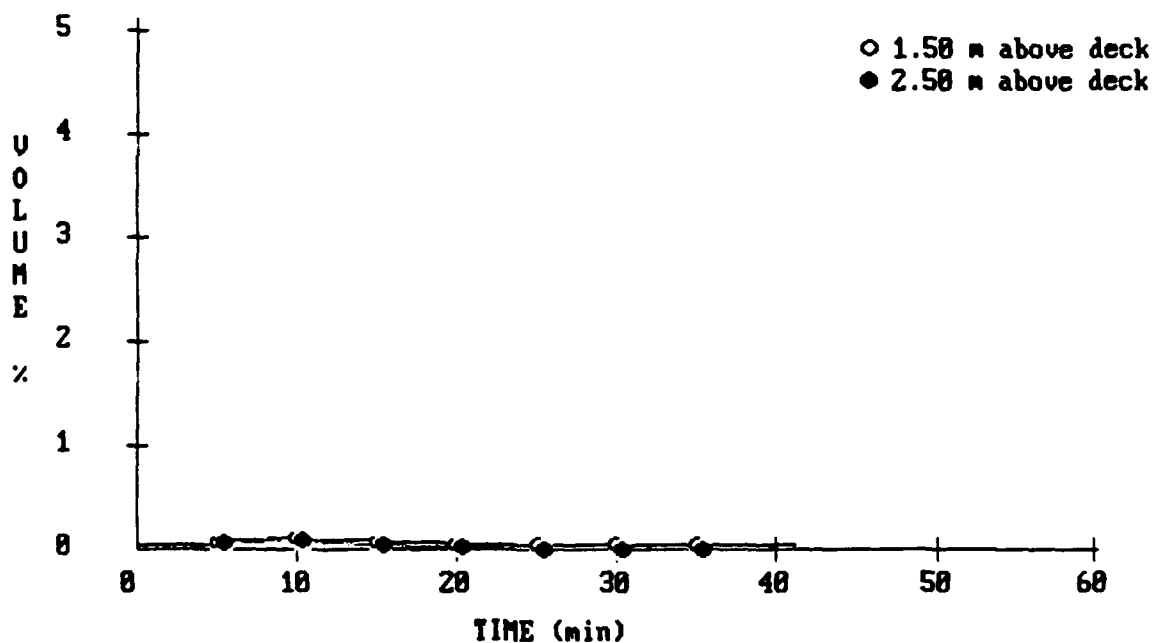


Fig. B-217- CO concentration in RICER 1 (2-76-2) during Test # 23

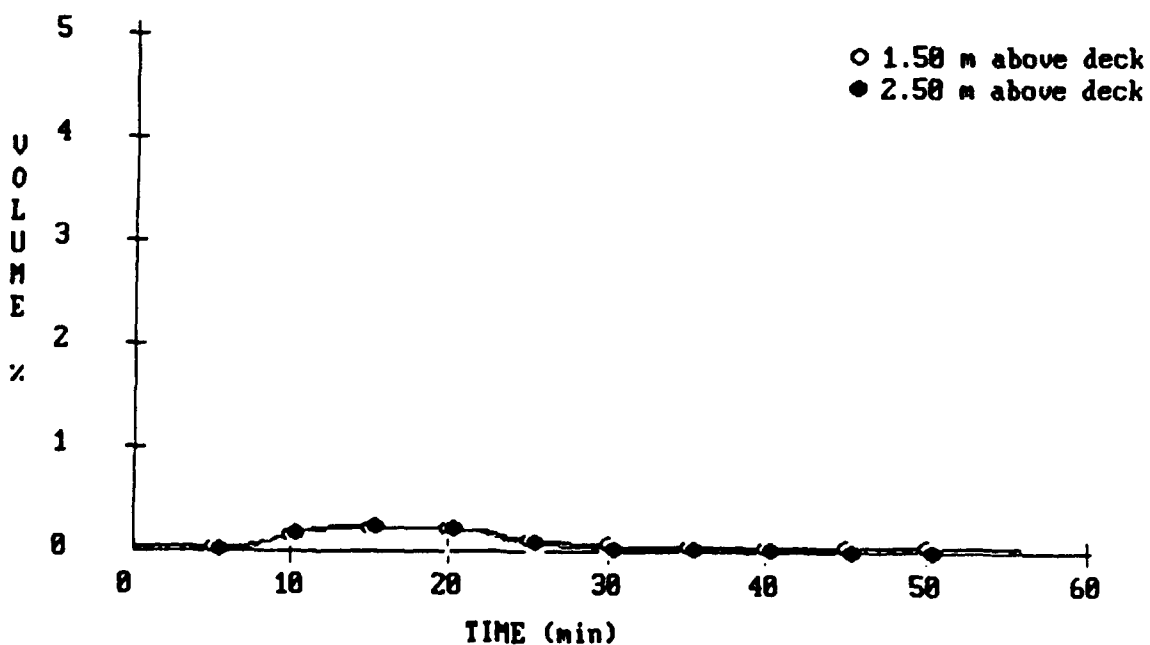


Fig. B-218- CO concentration in RICER 1 (2-76-2) during Test # 24

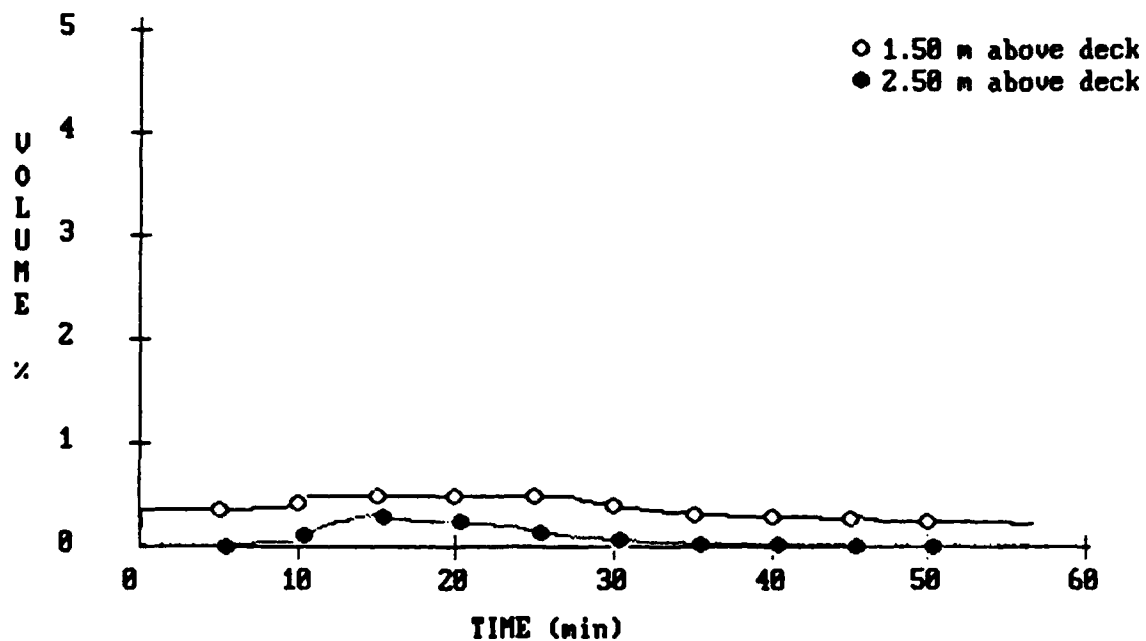


Fig. B-219- CO concentration in RICER 1 (2-76-2) during Test # 25

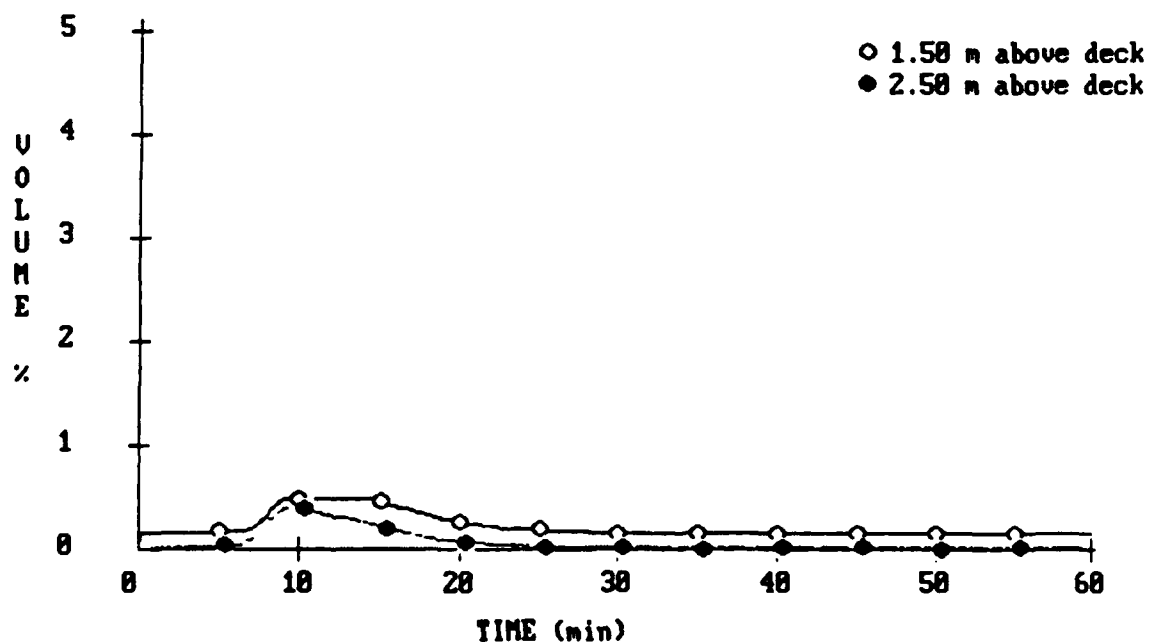


Fig. B-220- CO concentration in RICER 1 (2-76-2) during Test # 26

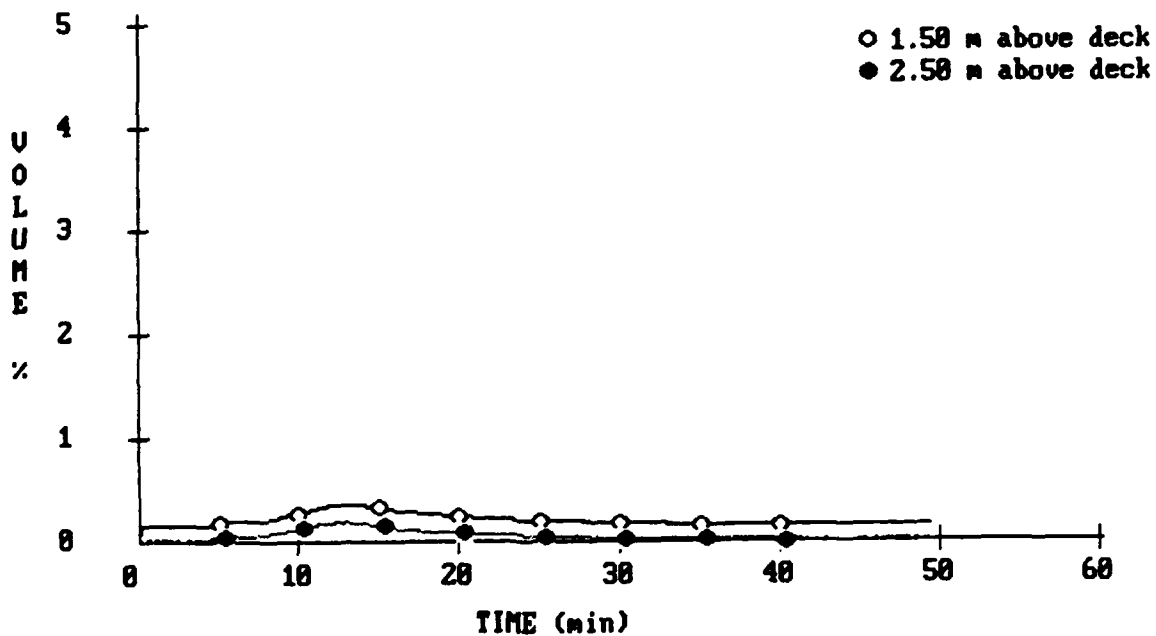


Fig. B-221- CO concentration in RICER 1 (2-76-2) during Test # 27

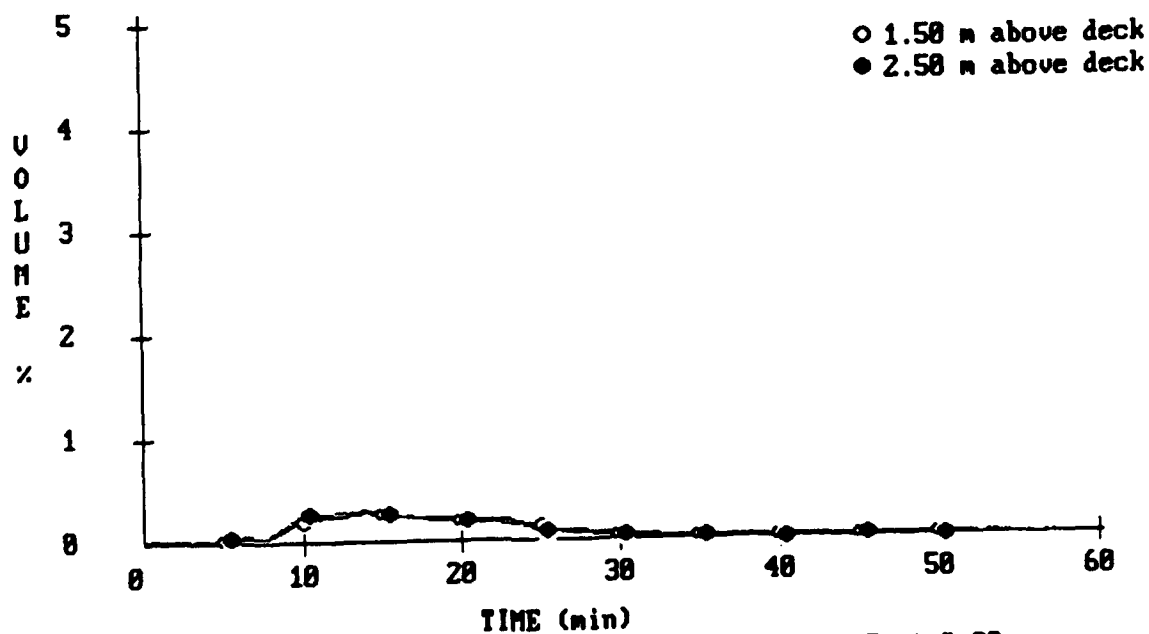


Fig. B-222- CO concentration in RICER 1 (2-76-2) during Test # 28

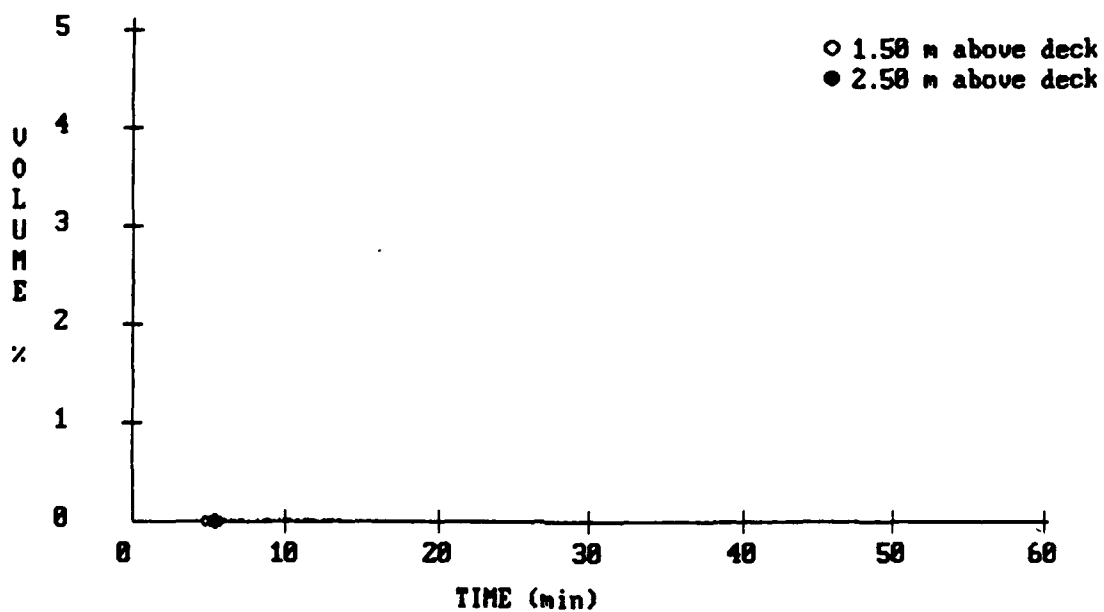


Fig. B-223- CO concentration in RICER 1 (2-76-2) during Test # 29

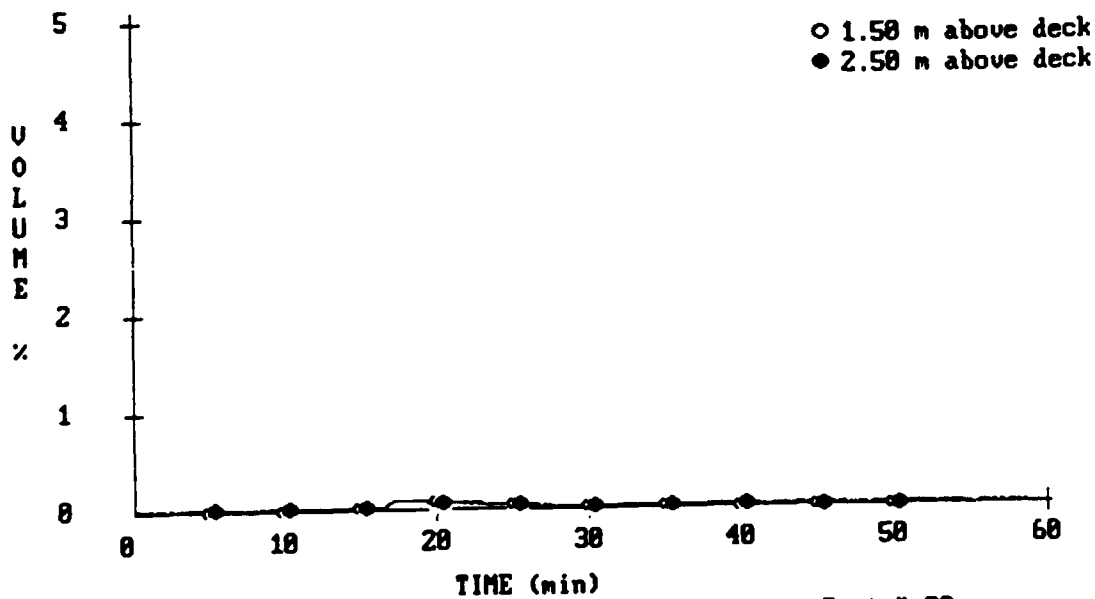


Fig. B-224- CO concentration in RICER 1 (2-76-2) during Test # 30

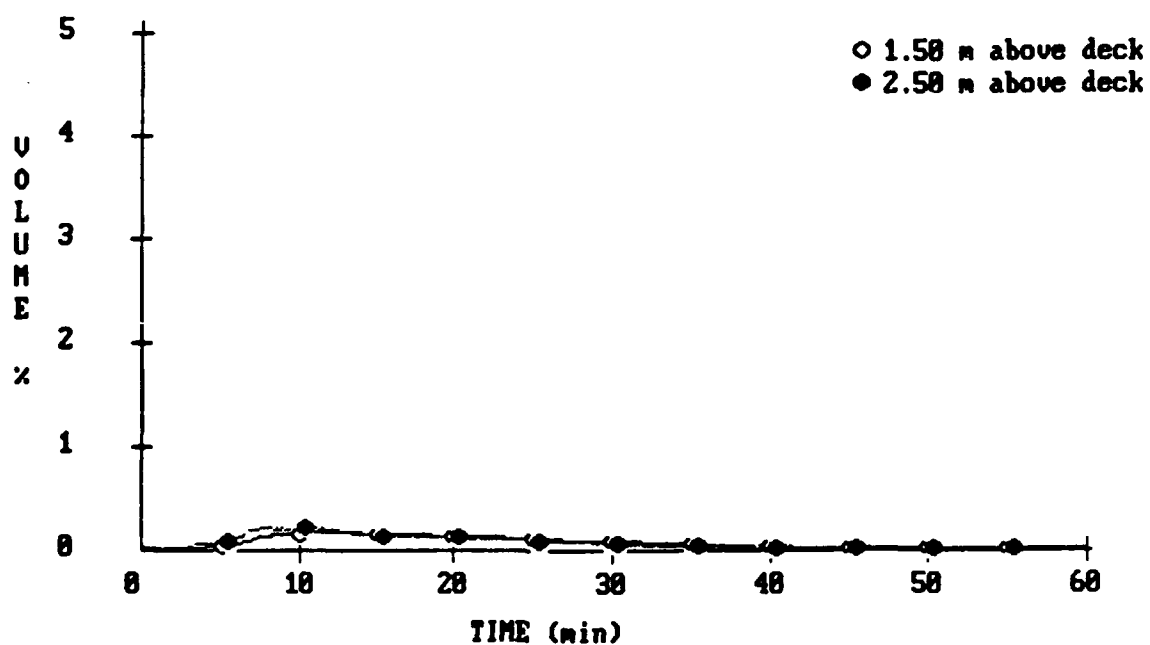


Fig. B-225- CO concentration in RICER 1 (2-76-2) during Test # 31

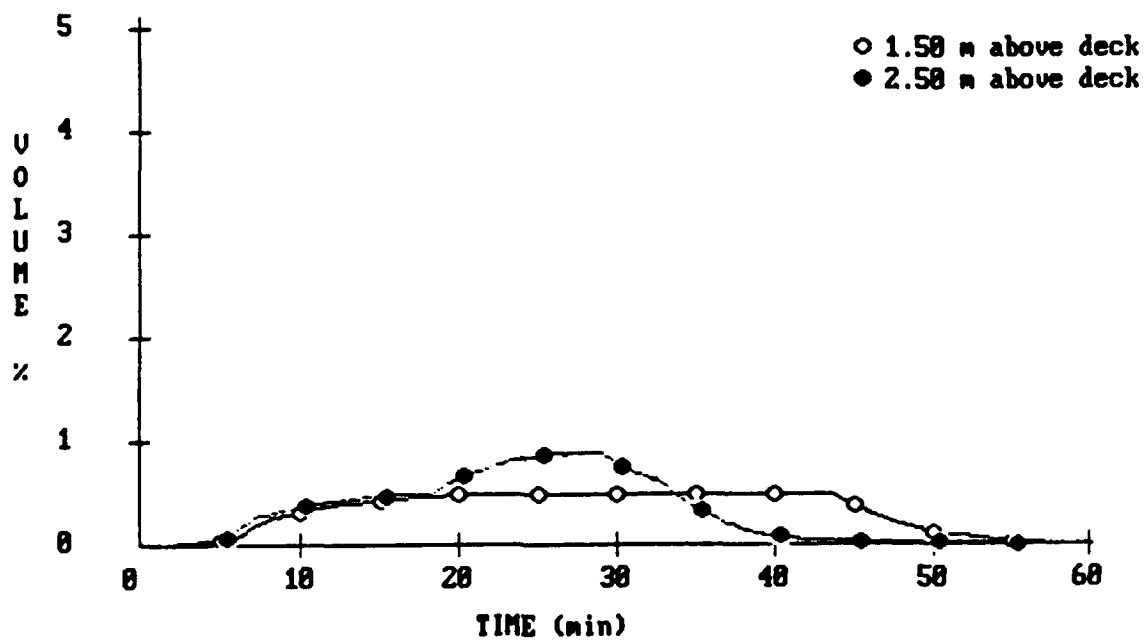


Fig. B-226- CO concentration in RICER 1 (2-76-2) during Test # 32

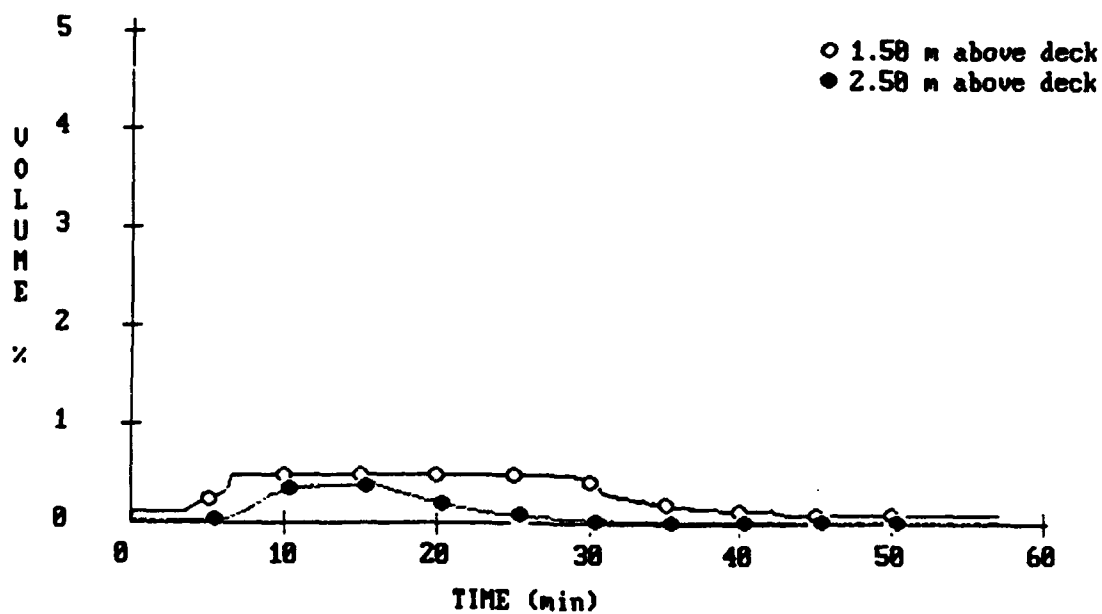


Fig. B-227- CO concentration in RICER 1 (2-76-2) during Test # 33

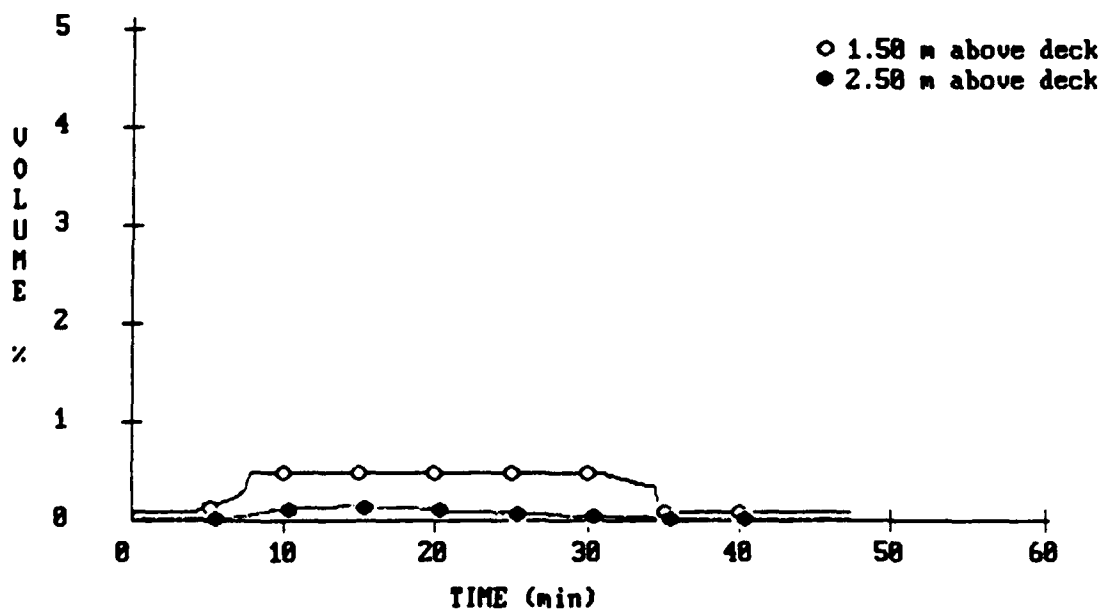


Fig. B-228- CO concentration in RICER 1 (2-76-2) during Test # 34

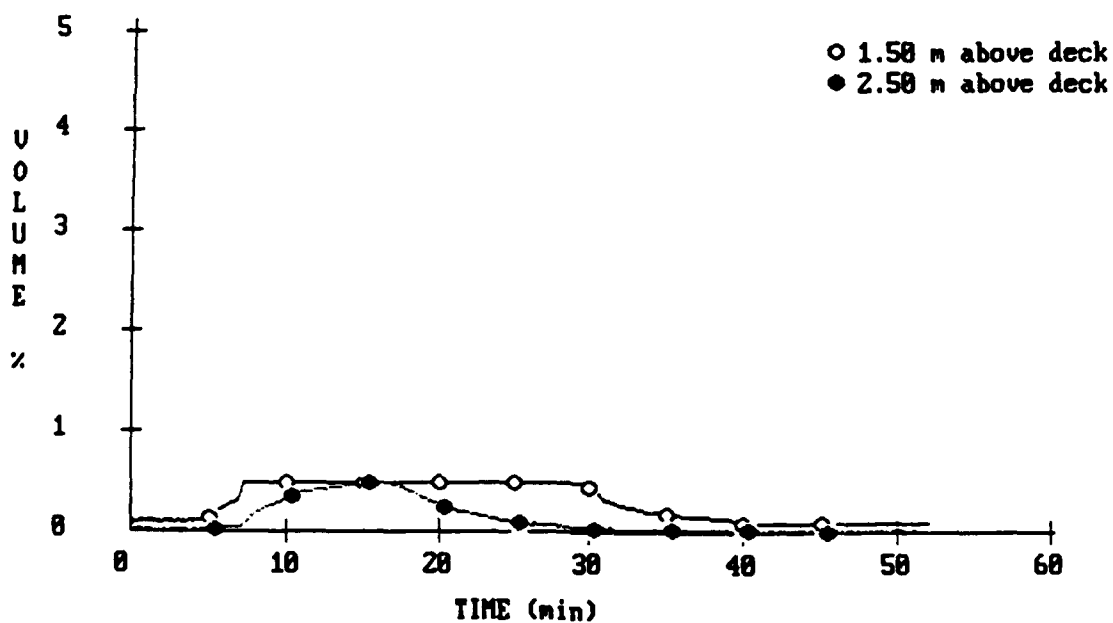


Fig. B-229- CO concentration in RICER 1 (2-76-2) during Test # 35

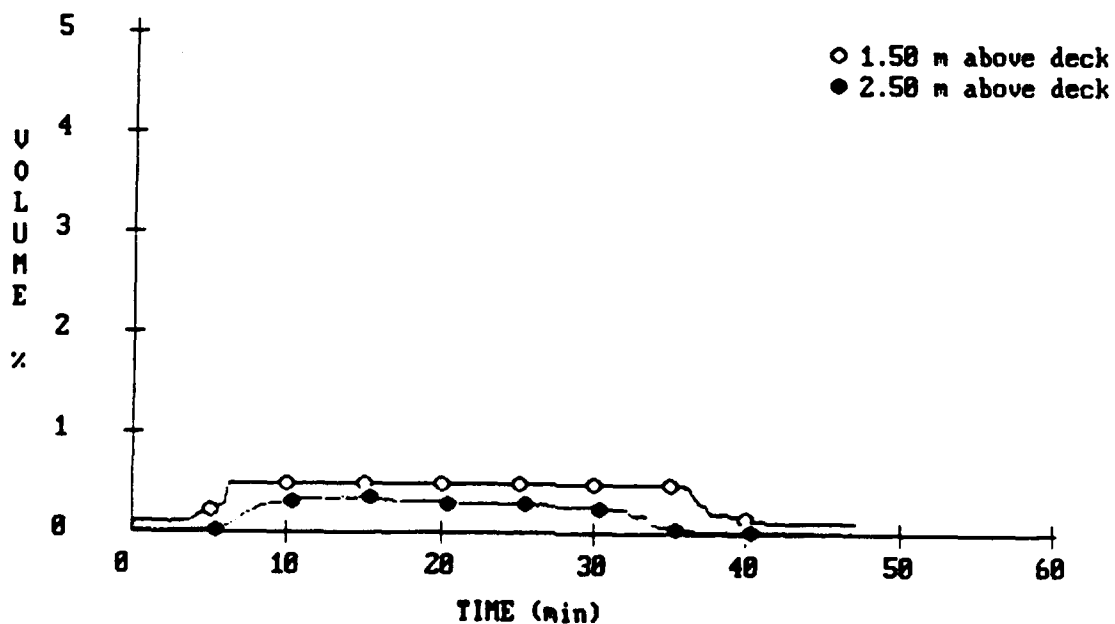


Fig. B-230- CO concentration in RICER 1 (2-76-2) during Test # 36

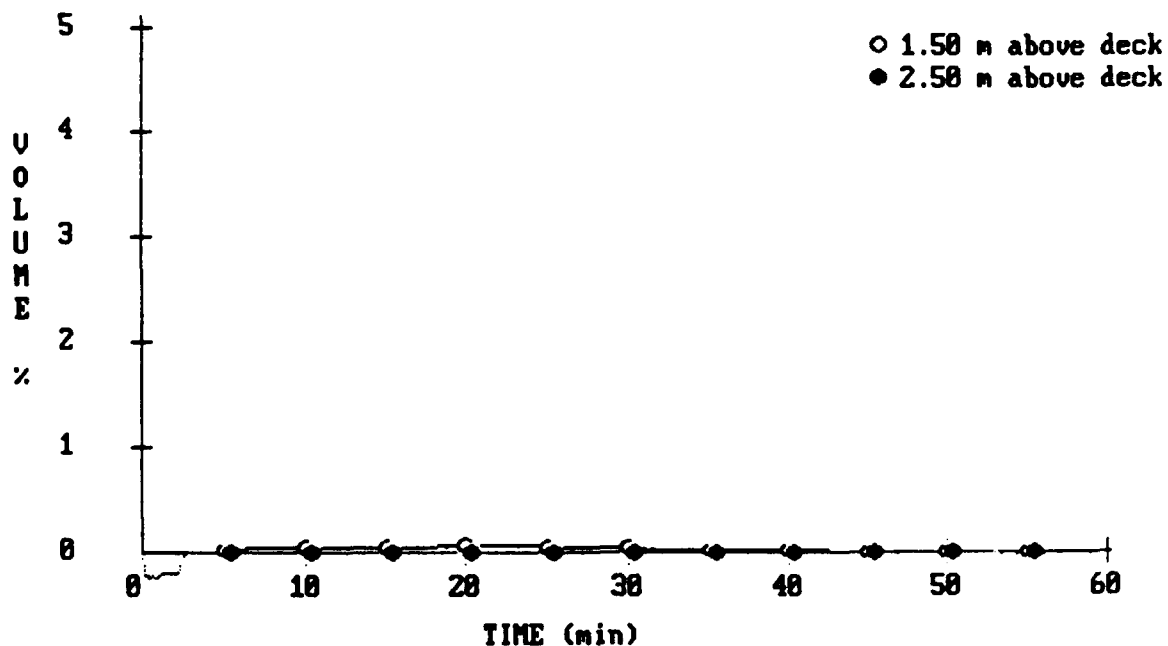


Fig. B-231- CO concentration in RICER 1 (2-76-2) during Test # 37

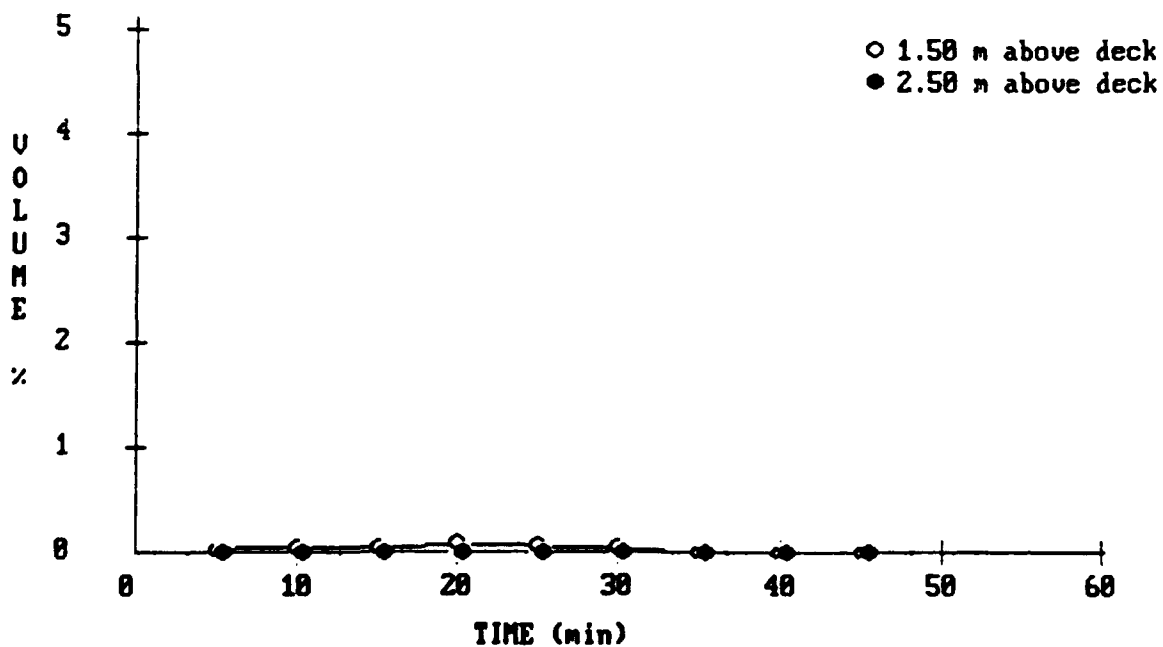


Fig. B-232- CO concentration in RICER 1 (2-76-2) during Test # 38



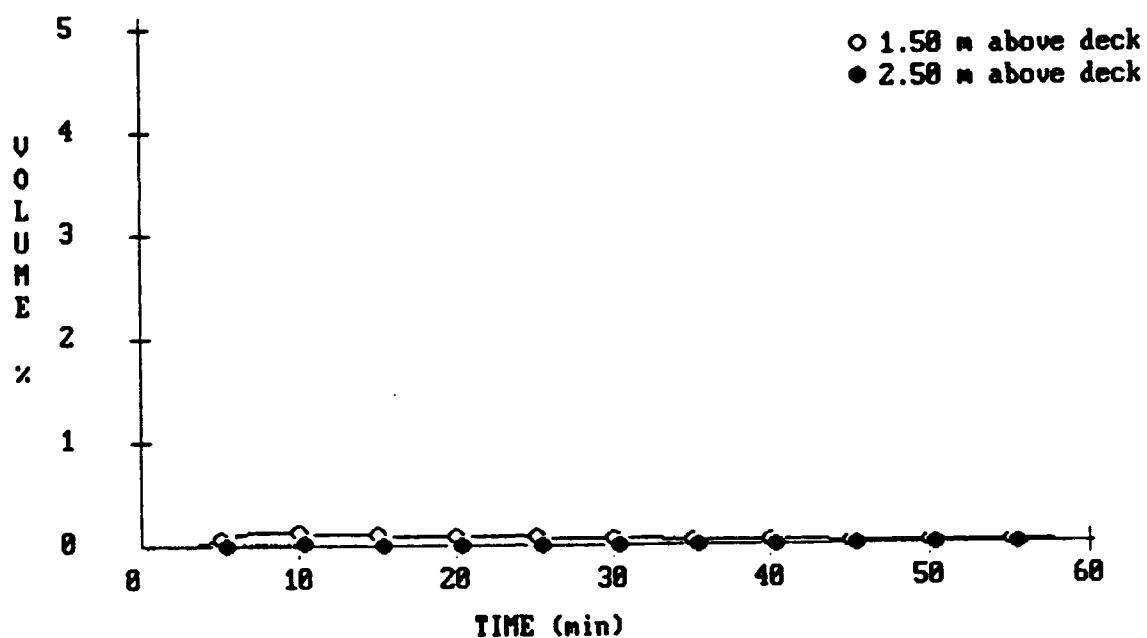


Fig. B-233- CO concentration in RICER 1 (2-76-2) during Test # 39

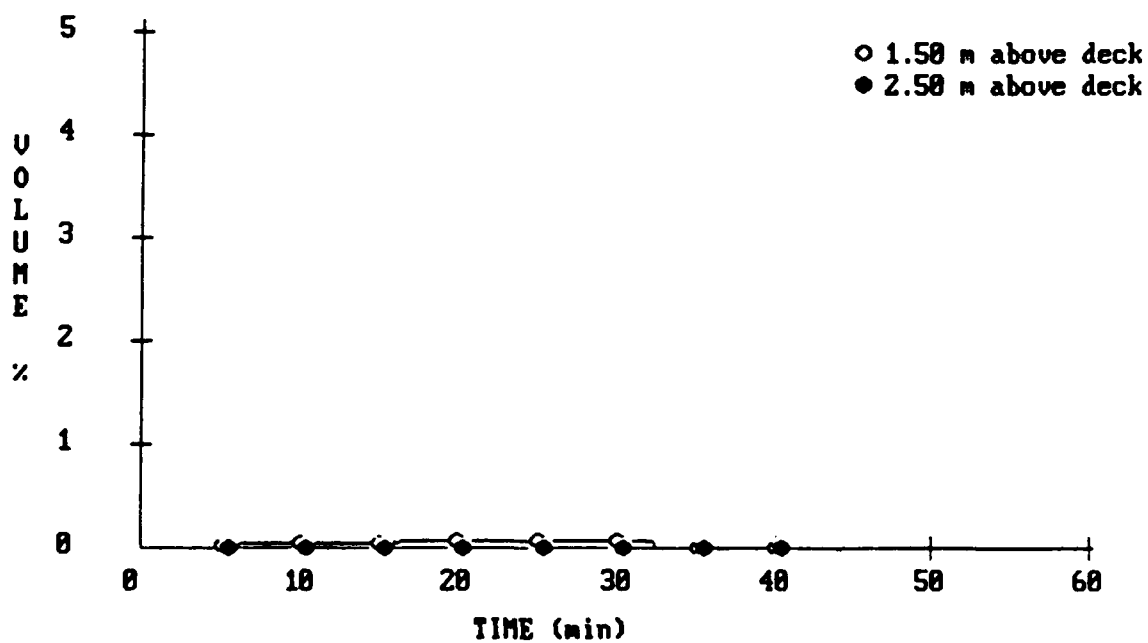


Fig. B-234- CO concentration in RICER 1 (2-76-2) during Test # 40

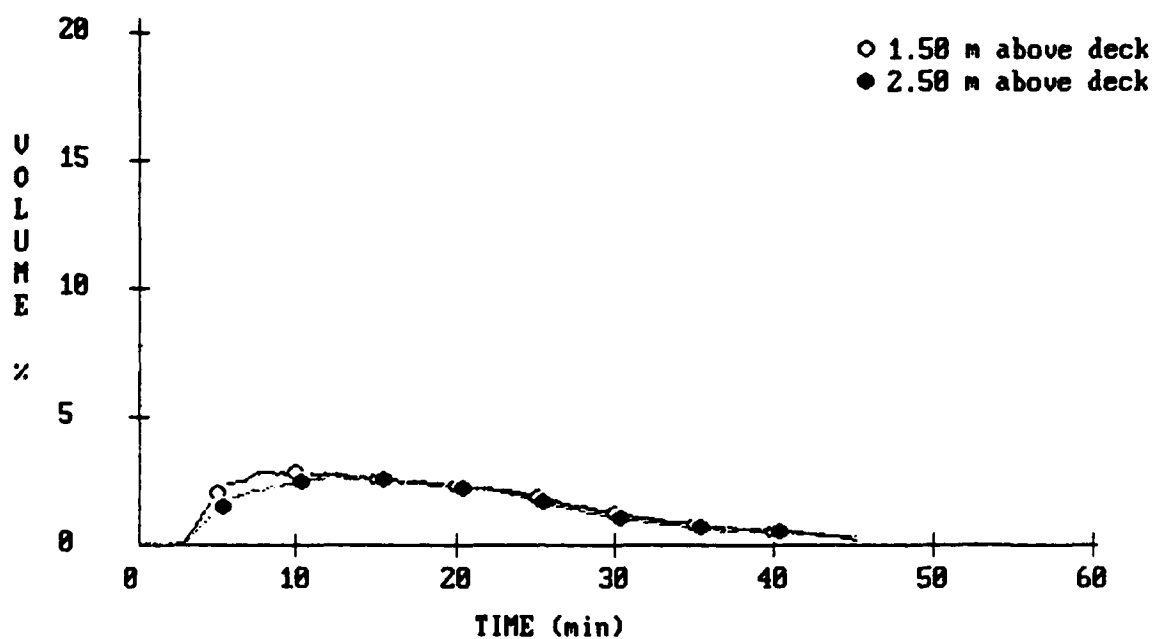


Fig. B-235- CO2 concentration in RICER 1 (2-76-2) during Test # 2

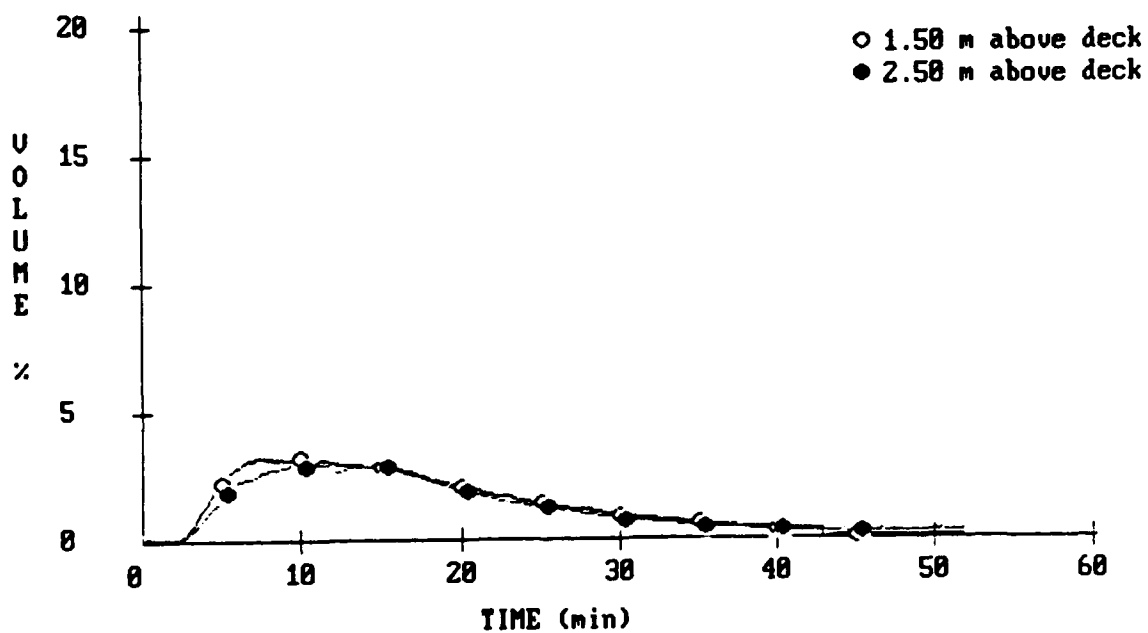


Fig. B-236- CO2 concentration in RICER 1 (2-76-2) during Test # 3

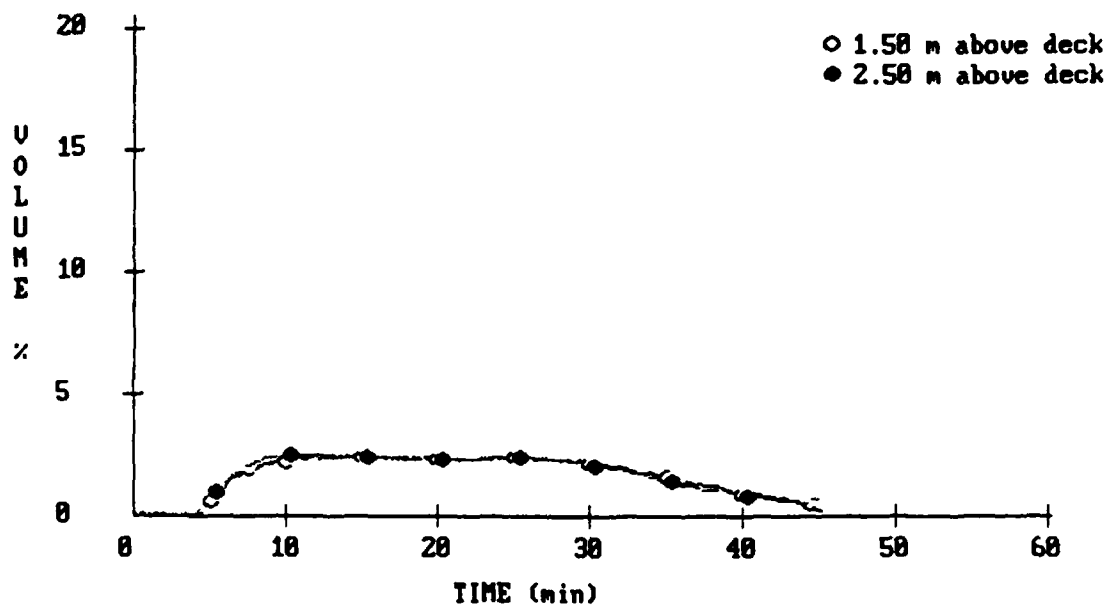


Fig. B-237- CO<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 4

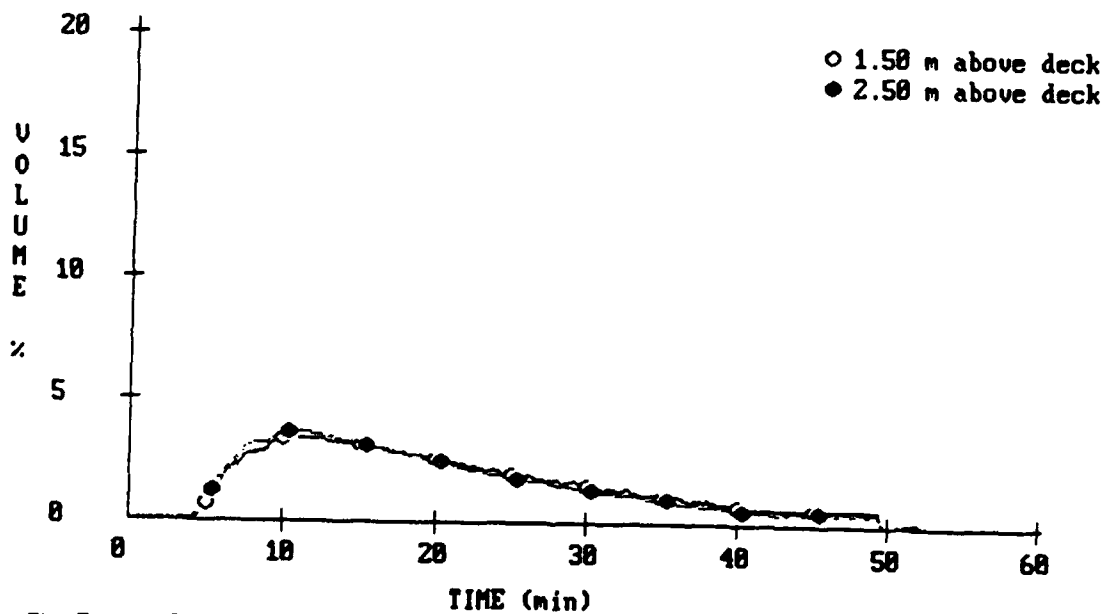


Fig. B-238- CO<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 5

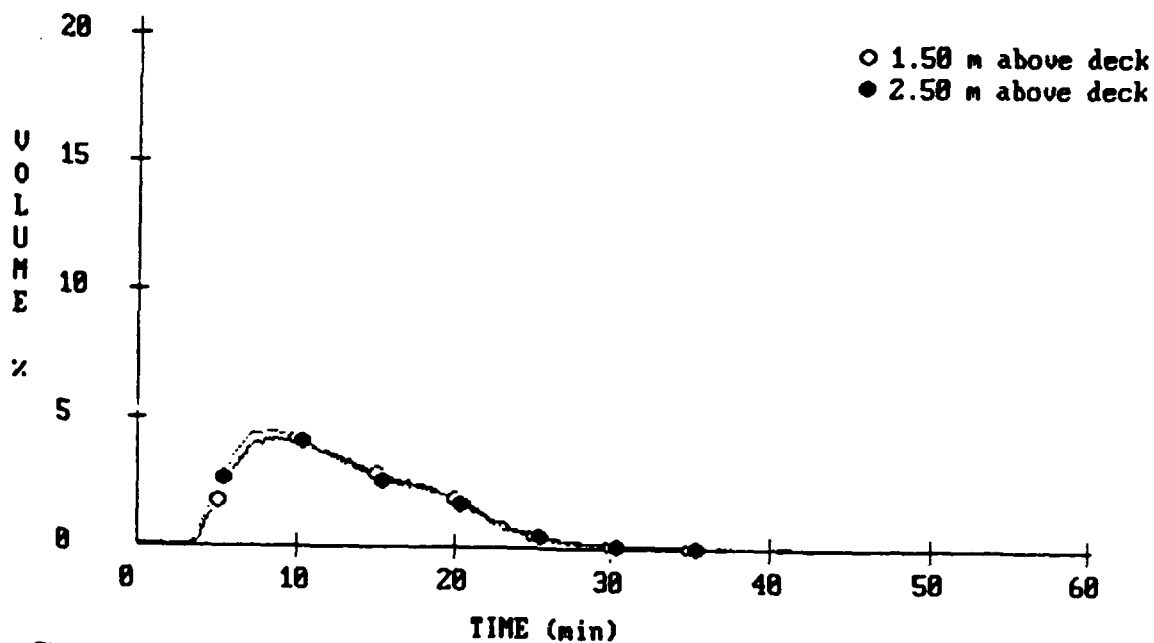


Fig. B-239- CO2 concentration in RICER 1 (2-76-2) during Test # 6

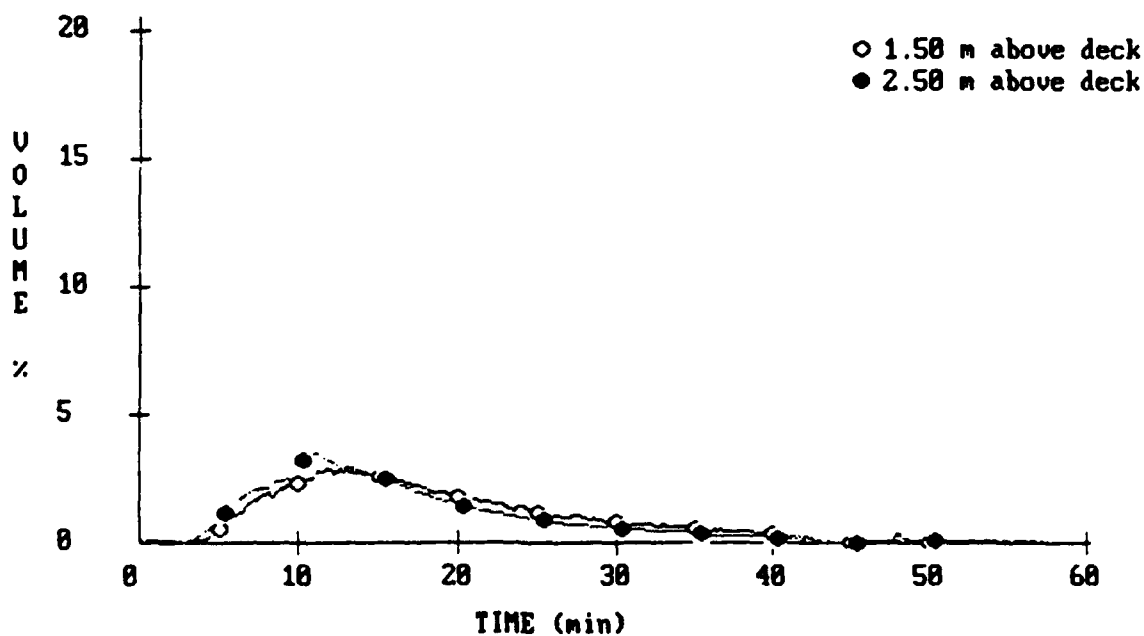


Fig. B-240- CO2 concentration in RICER 1 (2-76-2) during Test # 7

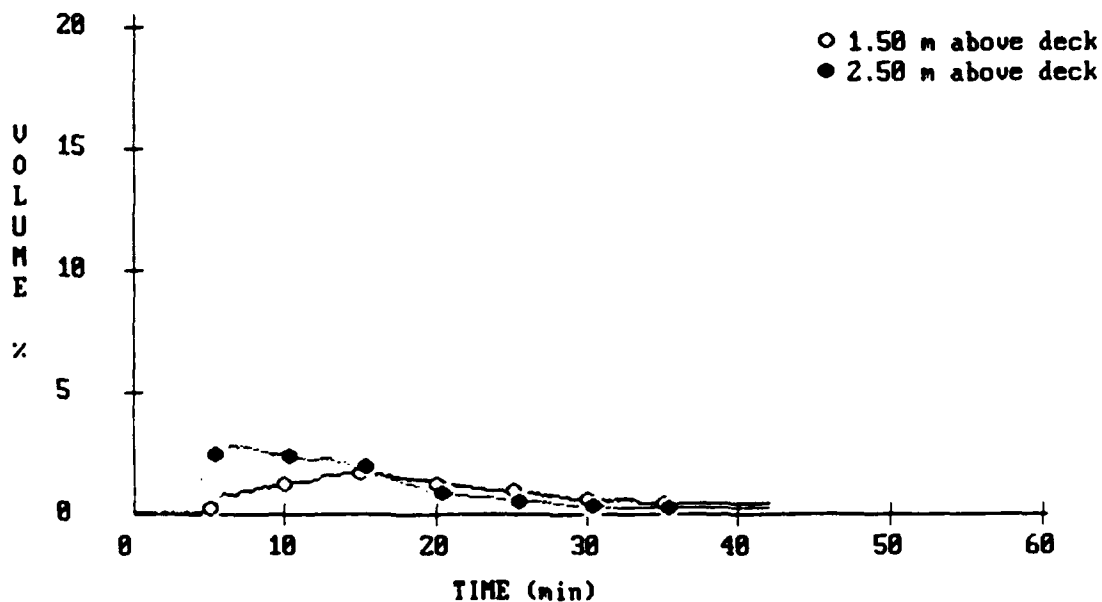


Fig. B-241- CO2 concentration in RICER 1 (2-76-2) during Test # 8

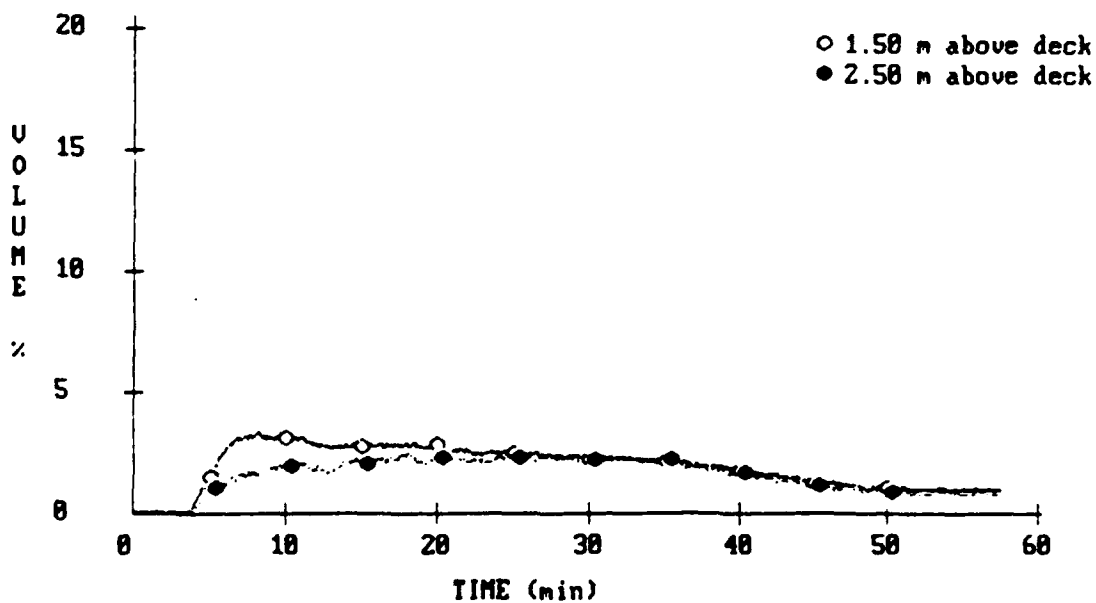


Fig. B-242- CO2 concentration in RICER 1 (2-76-2) during Test # 9

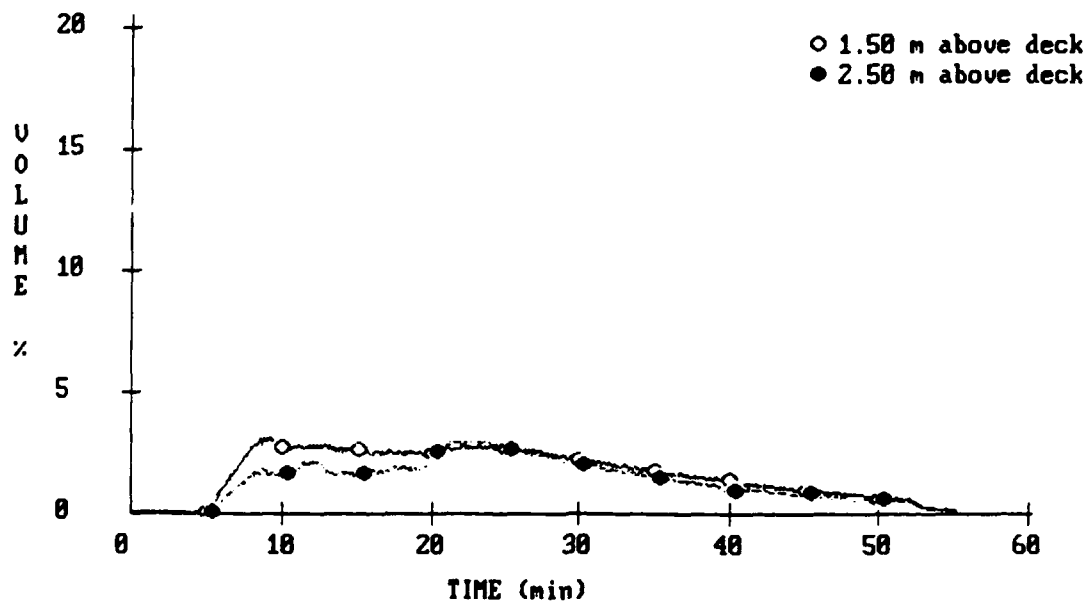


Fig. B-243- CO2 concentration in RICER 1 (2-76-2) during Test # 10

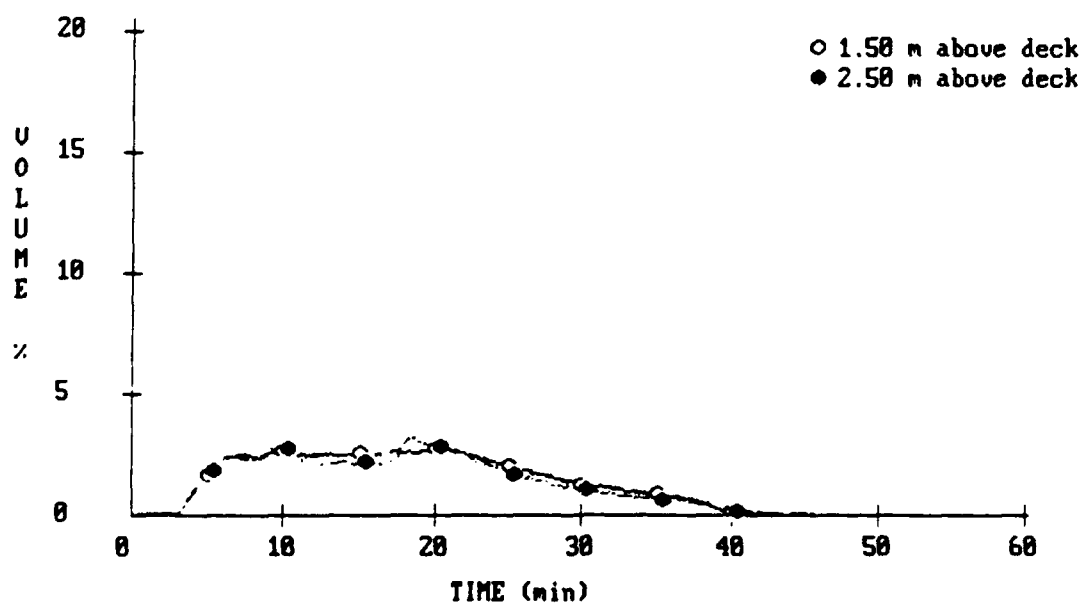


Fig. B-244- CO2 concentration in RICER 1 (2-76-2) during Test # 11

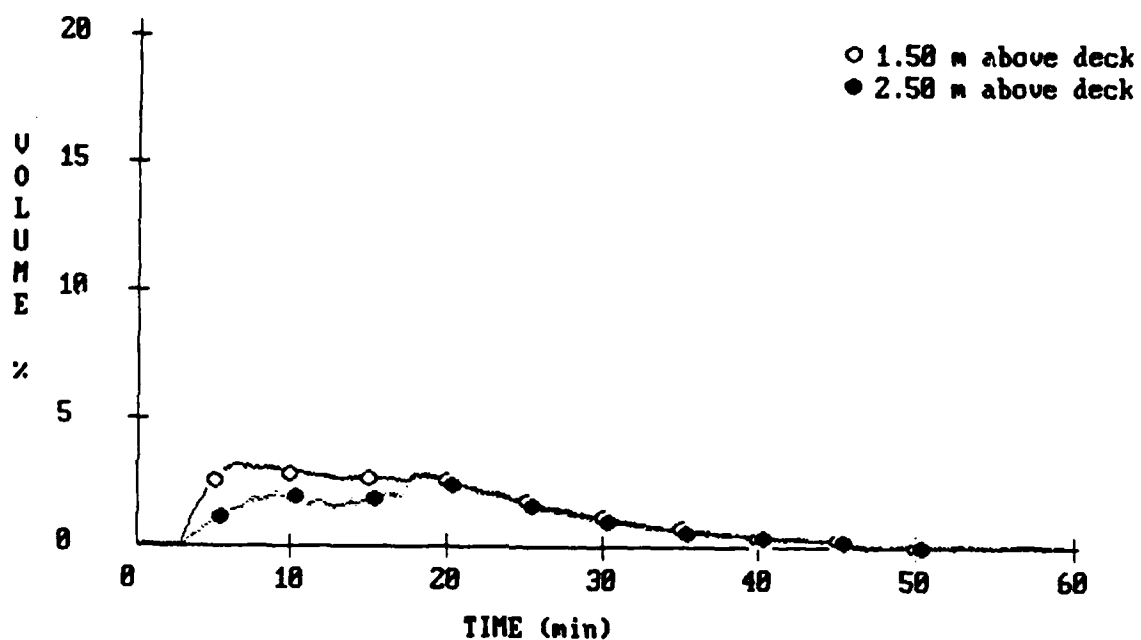


Fig. B-245- CO2 concentration in RICER 1 (2-76-2) during Test # 12

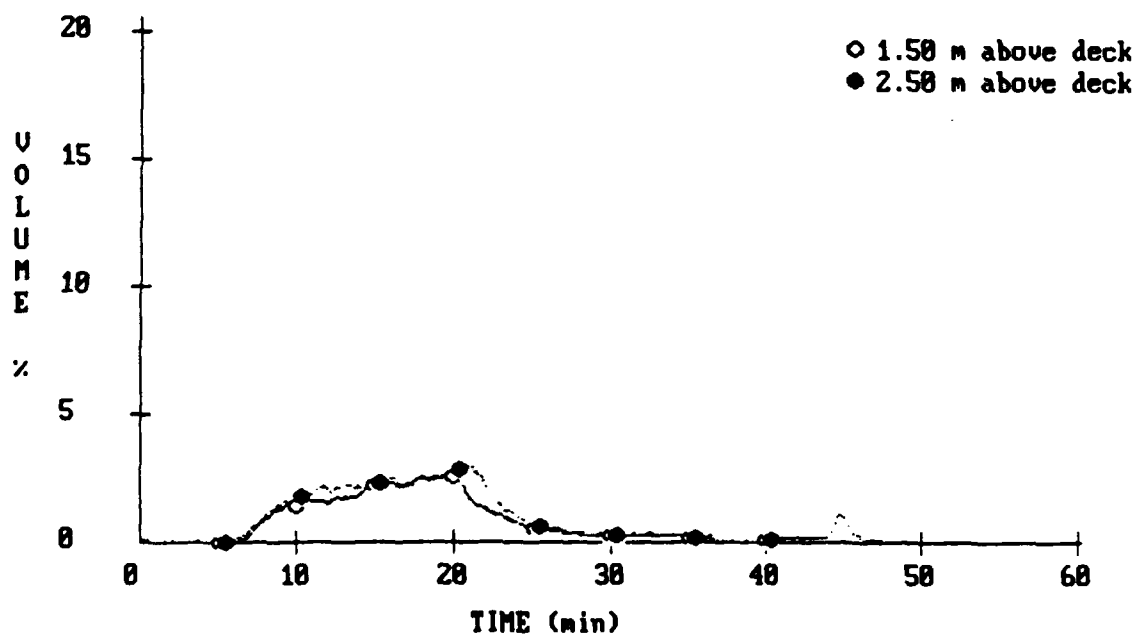


Fig. B-246- CO2 concentration in RICER 1 (2-76-2) during Test # 13

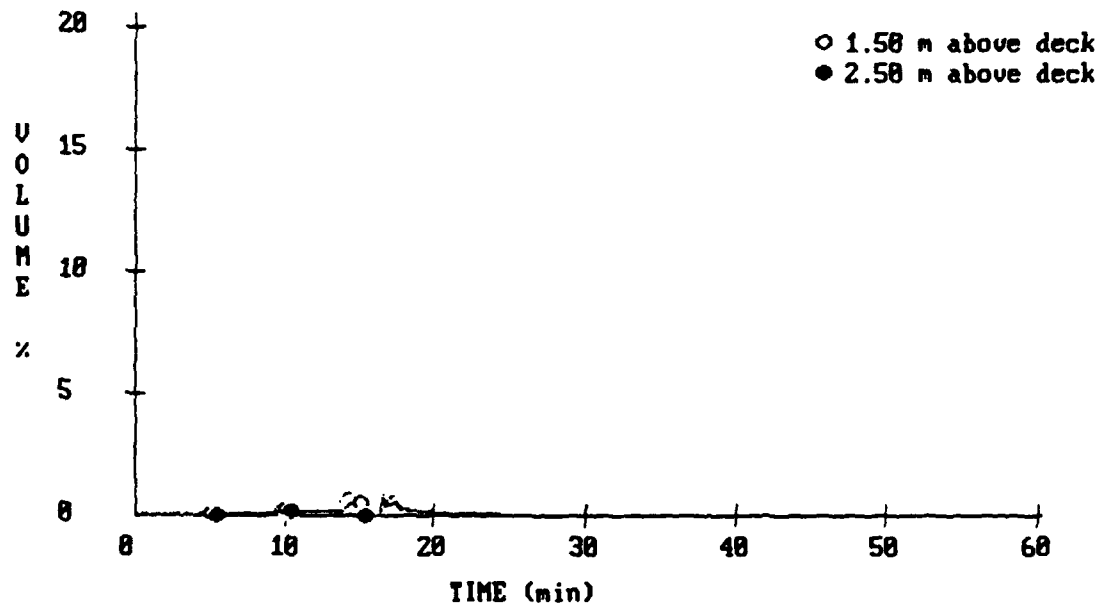


Fig. B-247- CO2 concentration in RICER 1 (2-76-2) during Test # 14

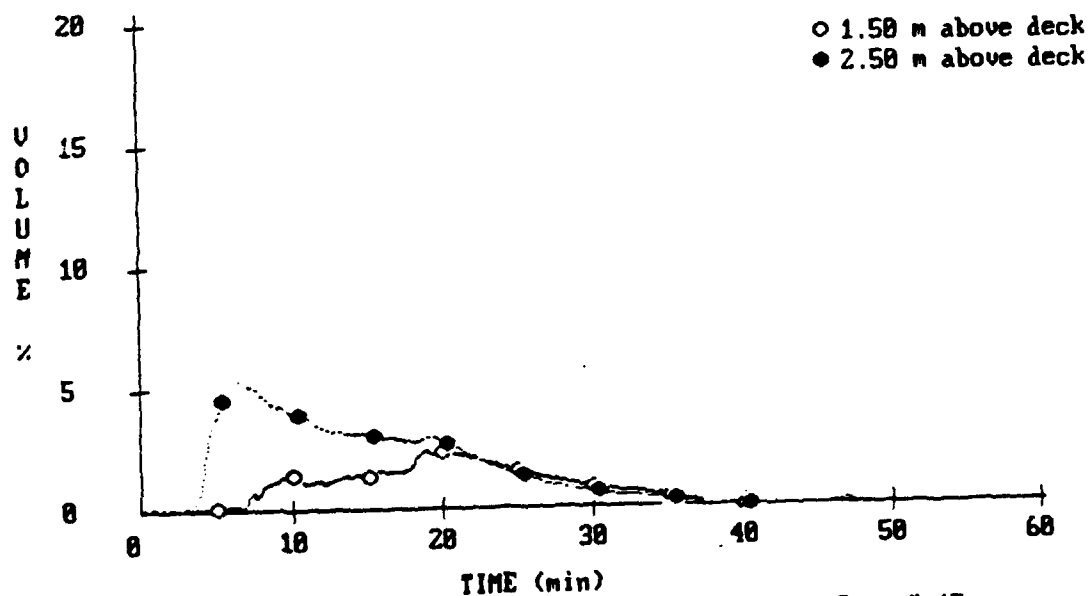


Fig. B-248- CO2 concentration in RICER 1 (2-76-2) during Test # 15



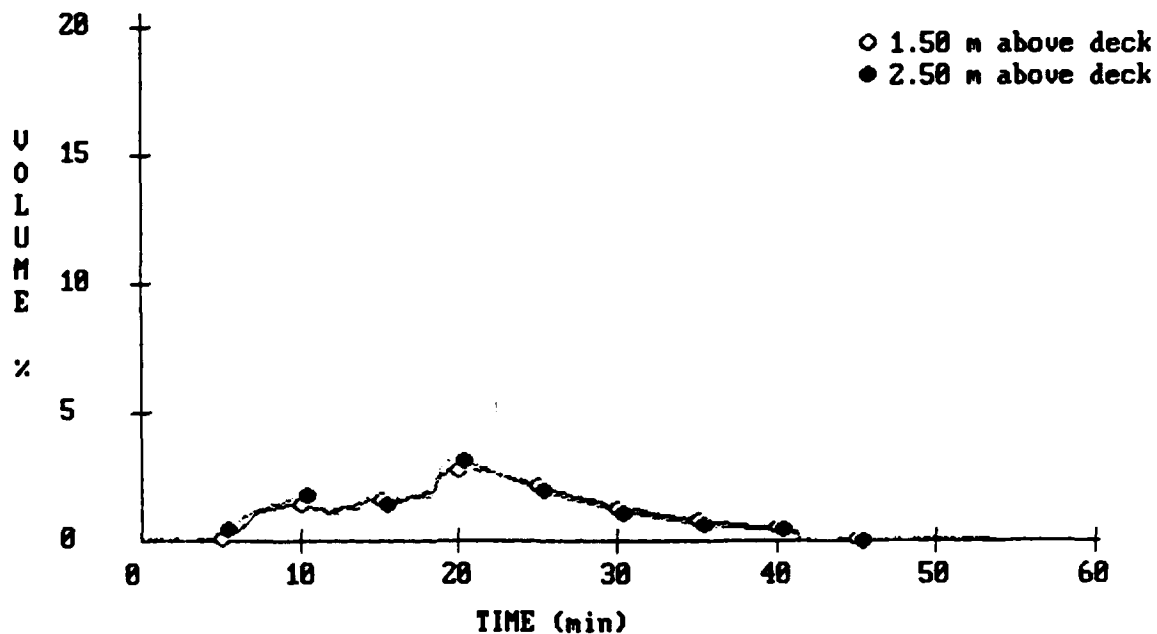


Fig. B-249- CO2 concentration in RICER 1 (2-76-2) during Test # 16

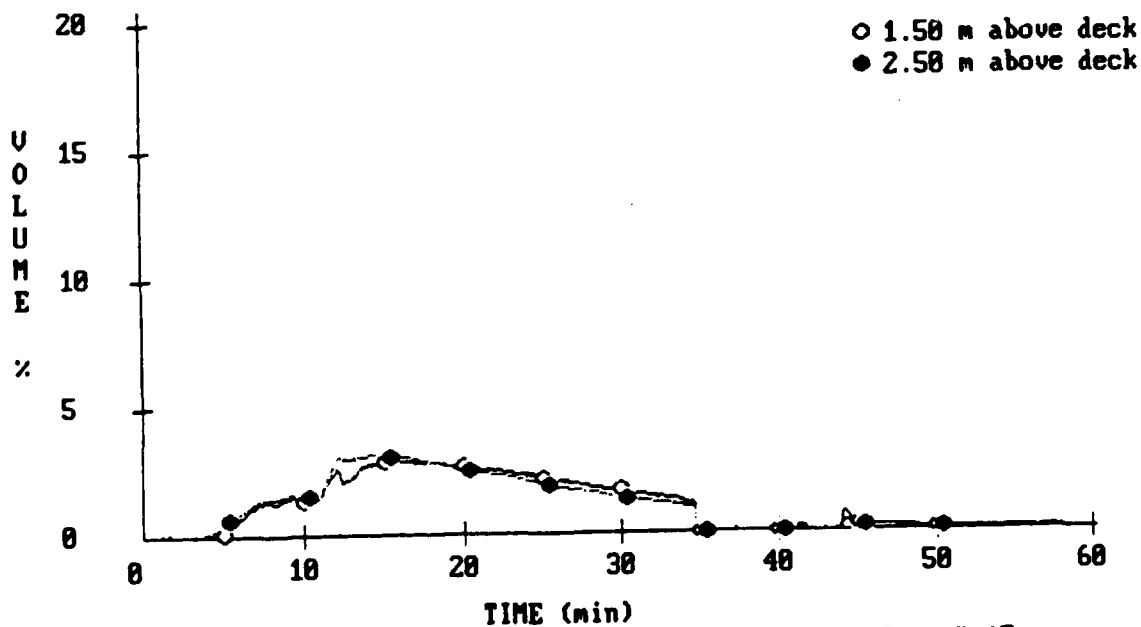


Fig. B-250- CO2 concentration in RICER 1 (2-76-2) during Test # 17

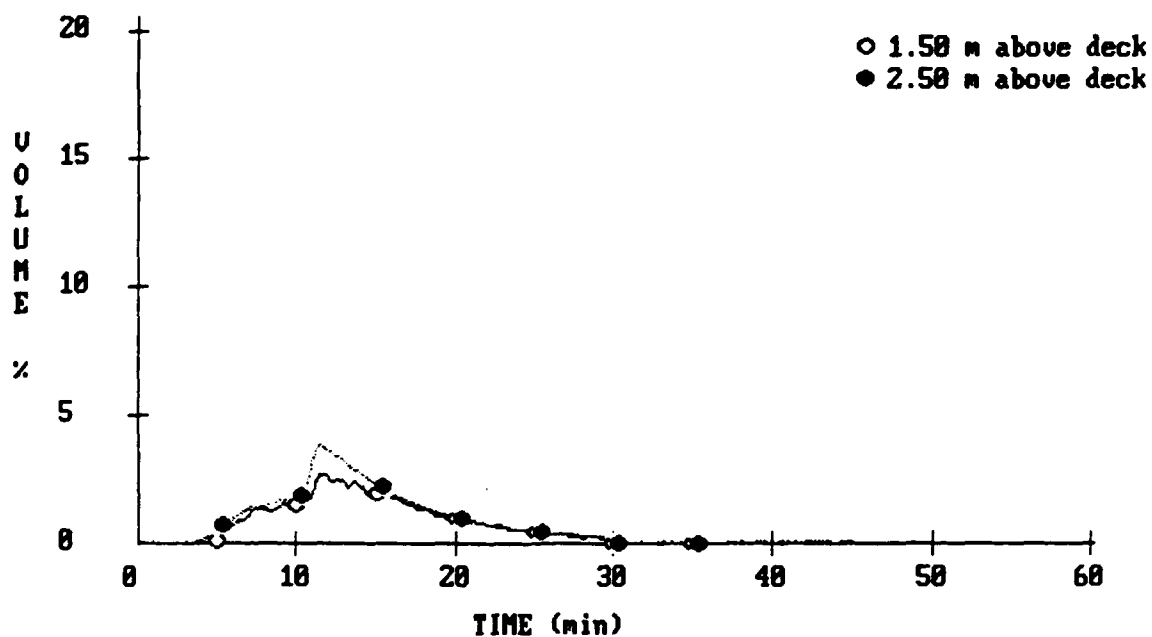


Fig. B-251- CO2 concentration in RICER 1 (2-76-2) during Test # 18

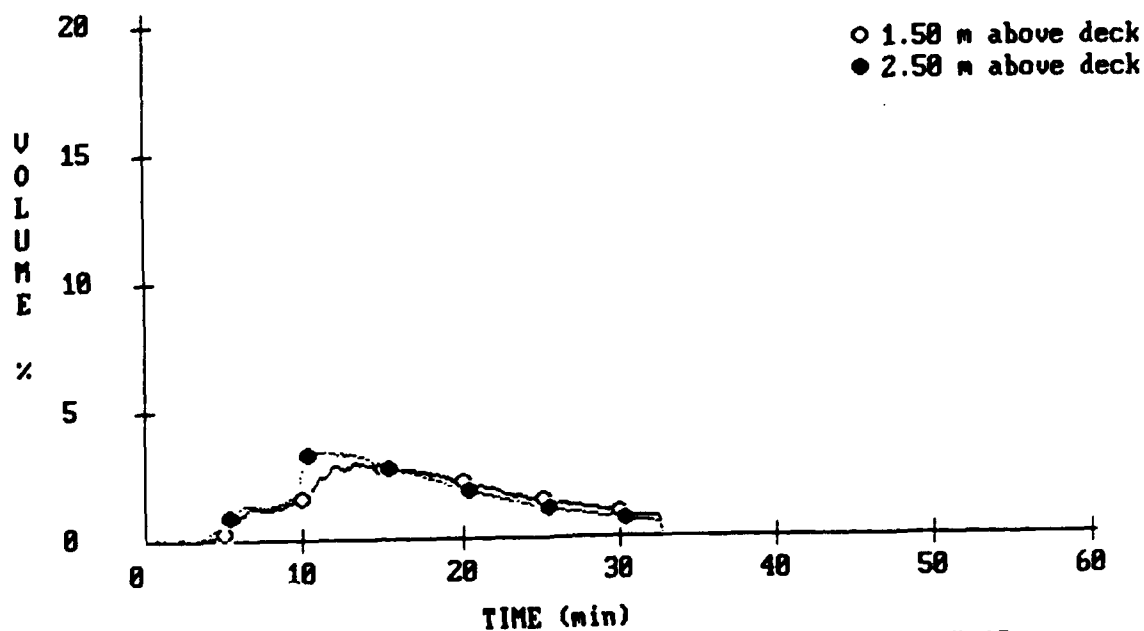


Fig. B-252- CO2 concentration in RICER 1 (2-76-2) during Test # 19

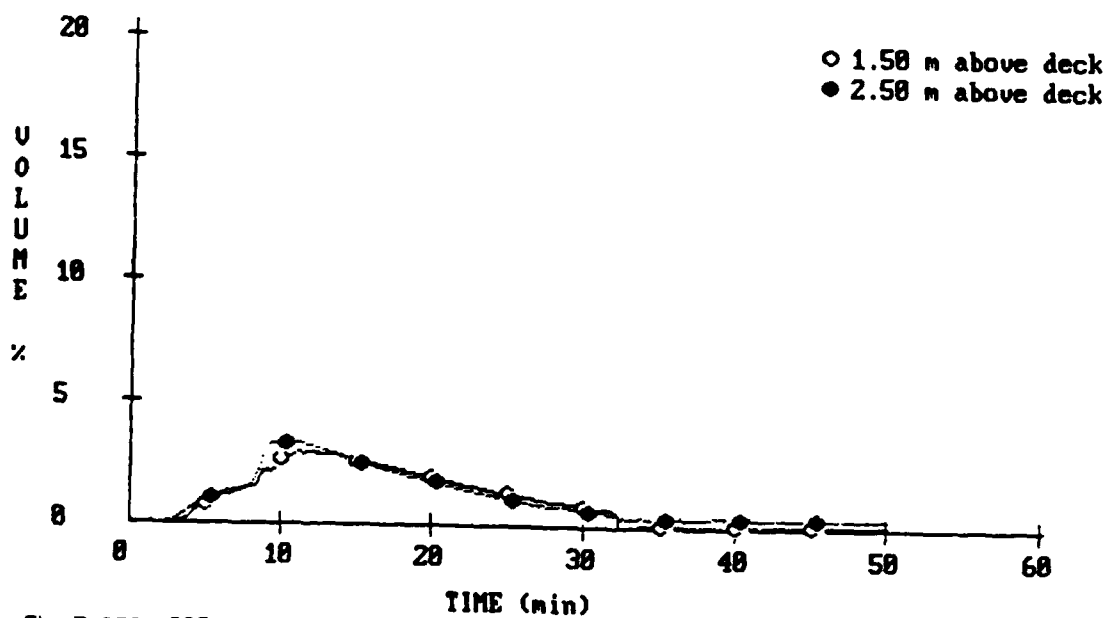


Fig. B-253- CO2 concentration in RICER 1 (2-76-2) during Test # 20

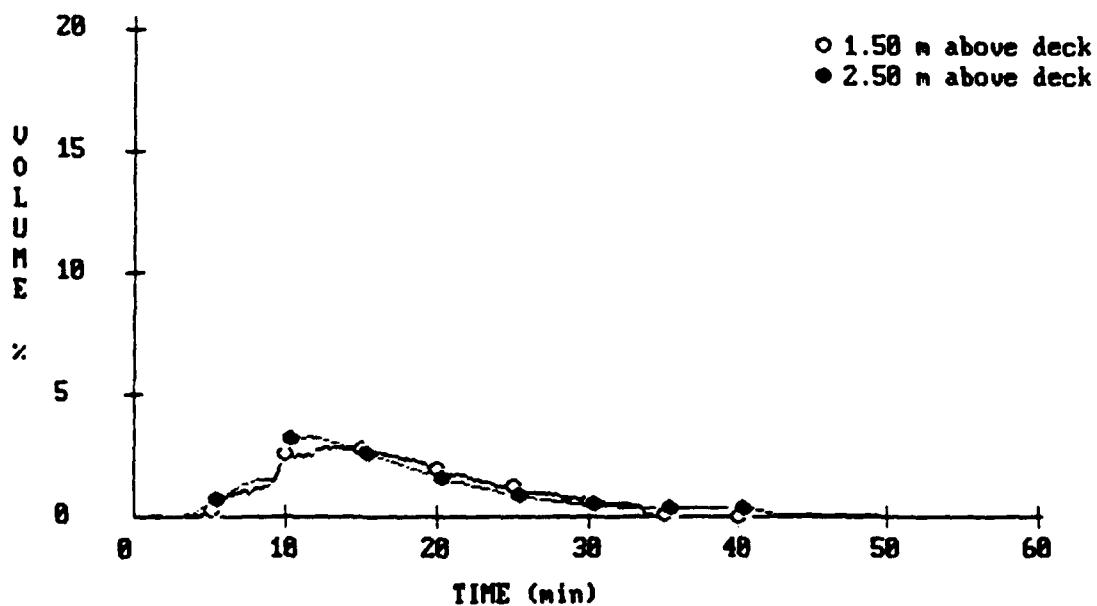


Fig. B-254- CO2 concentration in RICER 1 (2-76-2) during Test # 21

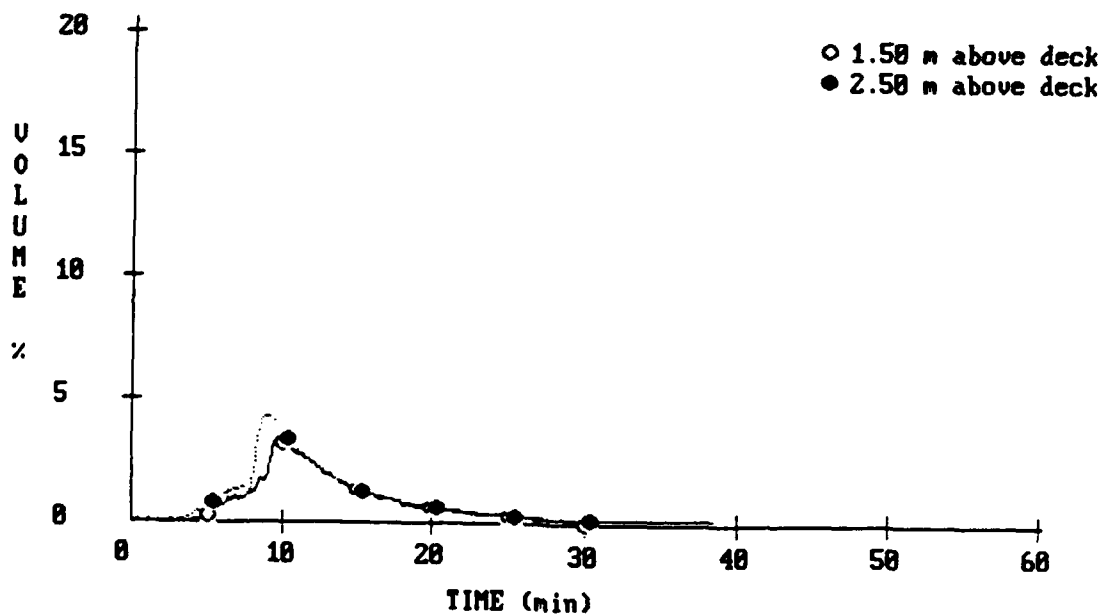


Fig. B-255- CO2 concentration in RICER 1 (2-76-2) during Test # 22

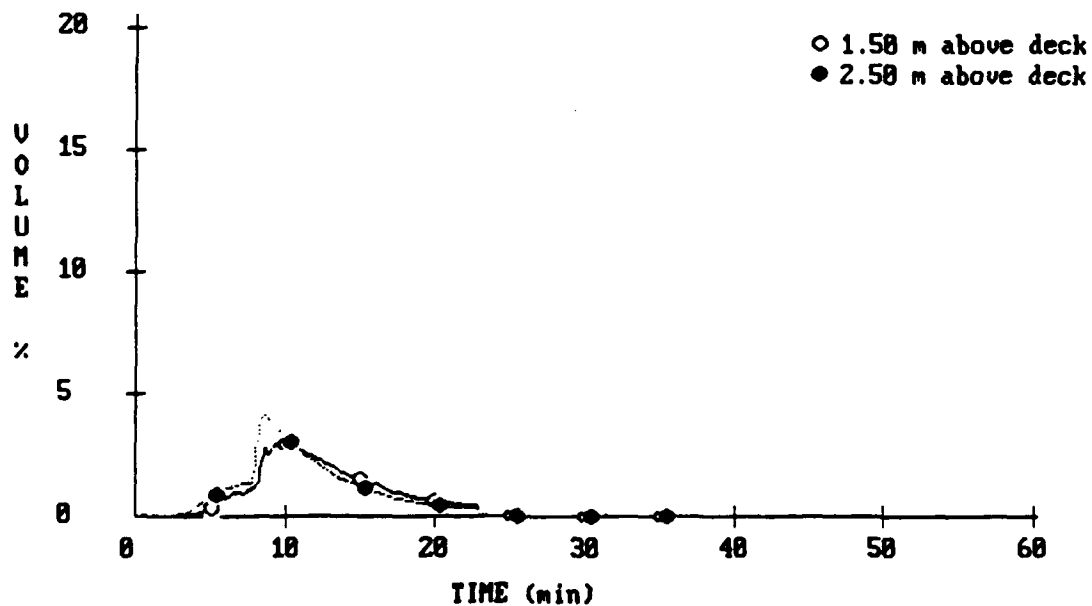


Fig. B-256- CO2 concentration in RICER 1 (2-76-2) during Test # 23

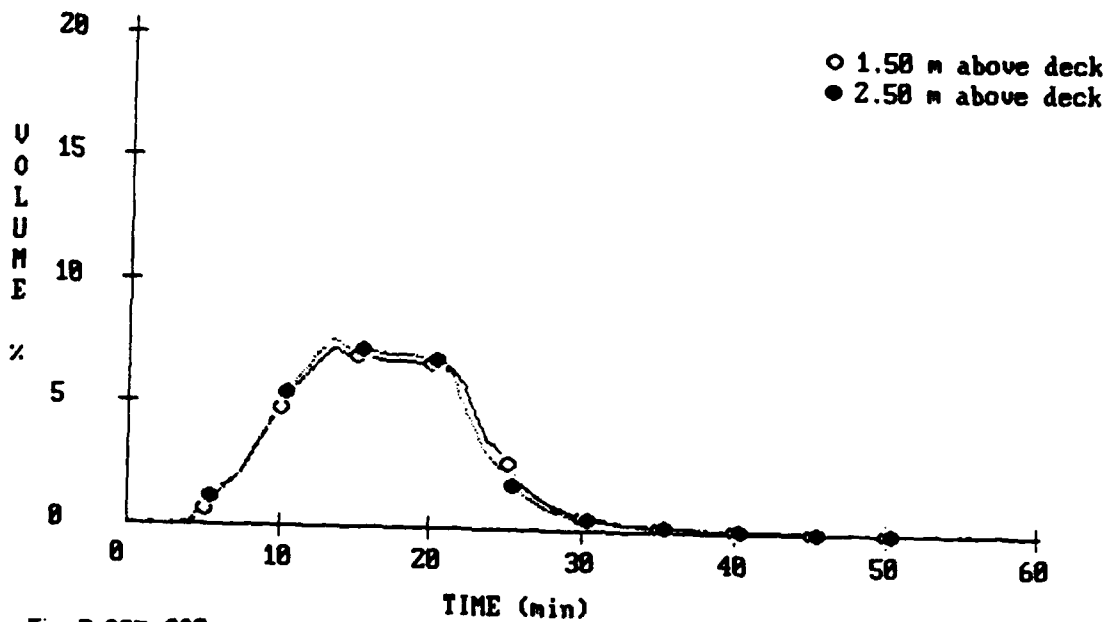


Fig. B-257- CO2 concentration in RICER 1 (2-76-2) during Test # 24

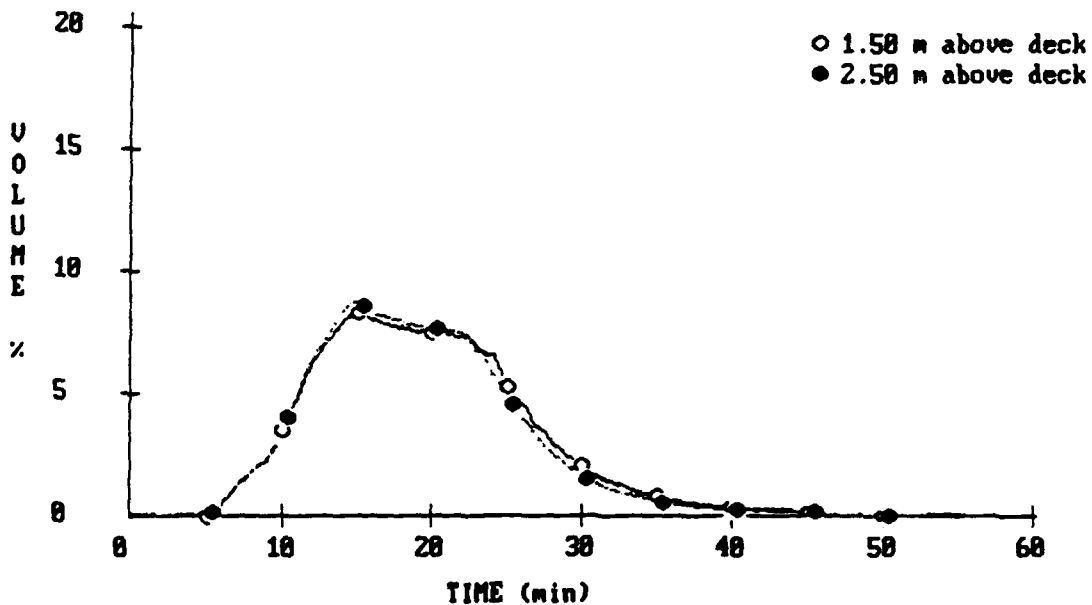


Fig. B-258- CO2 concentration in RICER 1 (2-76-2) during Test # 25

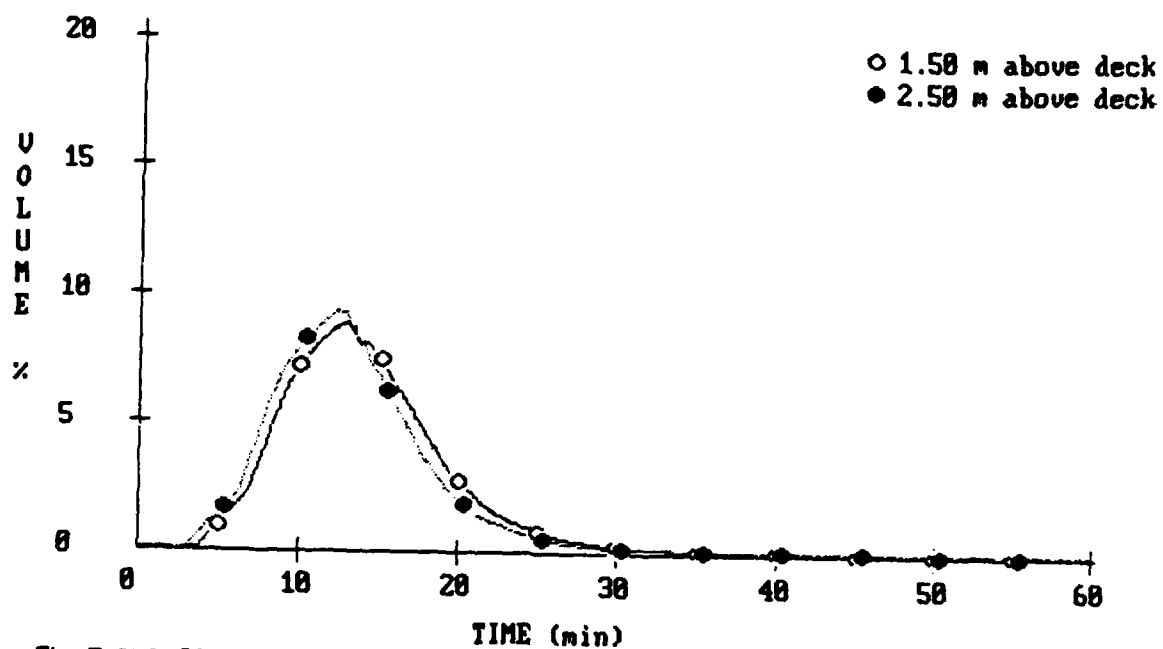


Fig. B-259- CO2 concentration in RICER 1 (2-76-2) during Test # 26

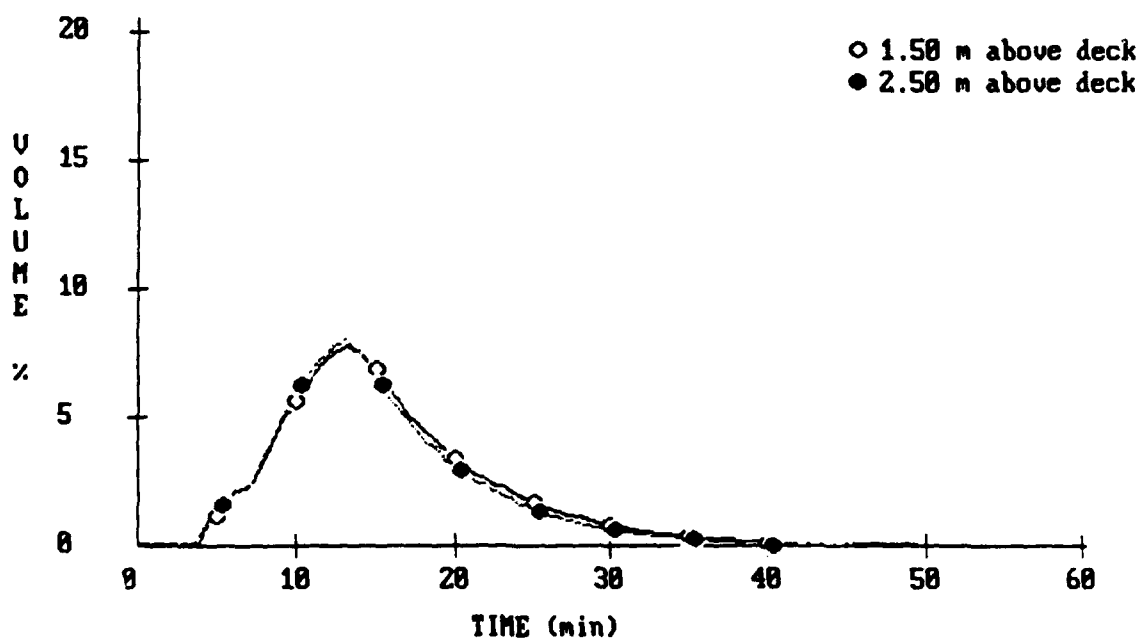


Fig. B-260- CO2 concentration in RICER 1 (2-76-2) during Test # 27

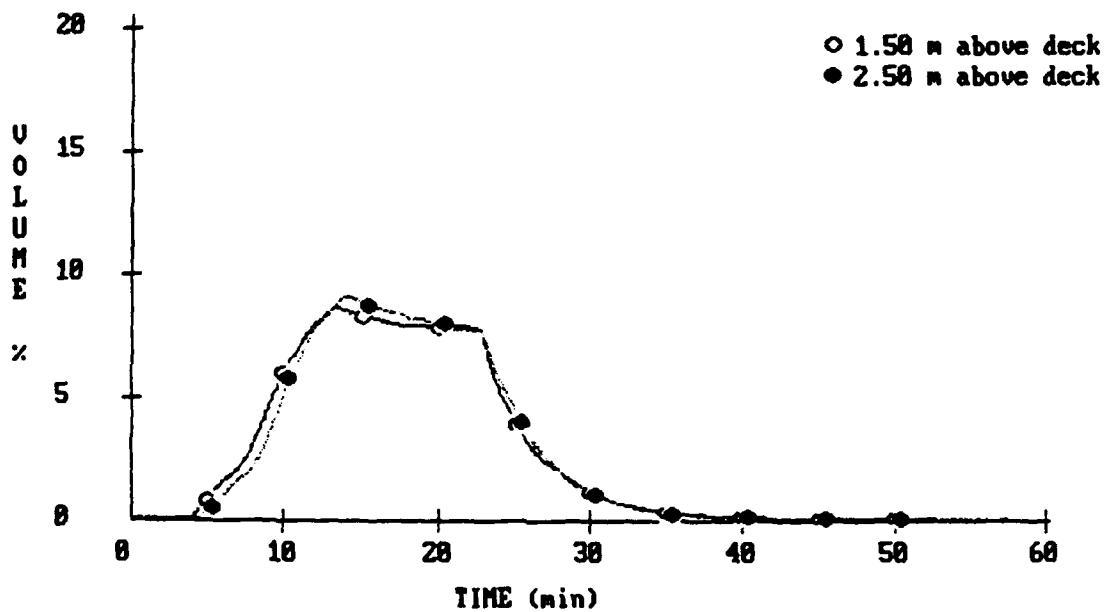


Fig. B-261- CO2 concentration in RICER 1 (2-76-2) during Test # 28

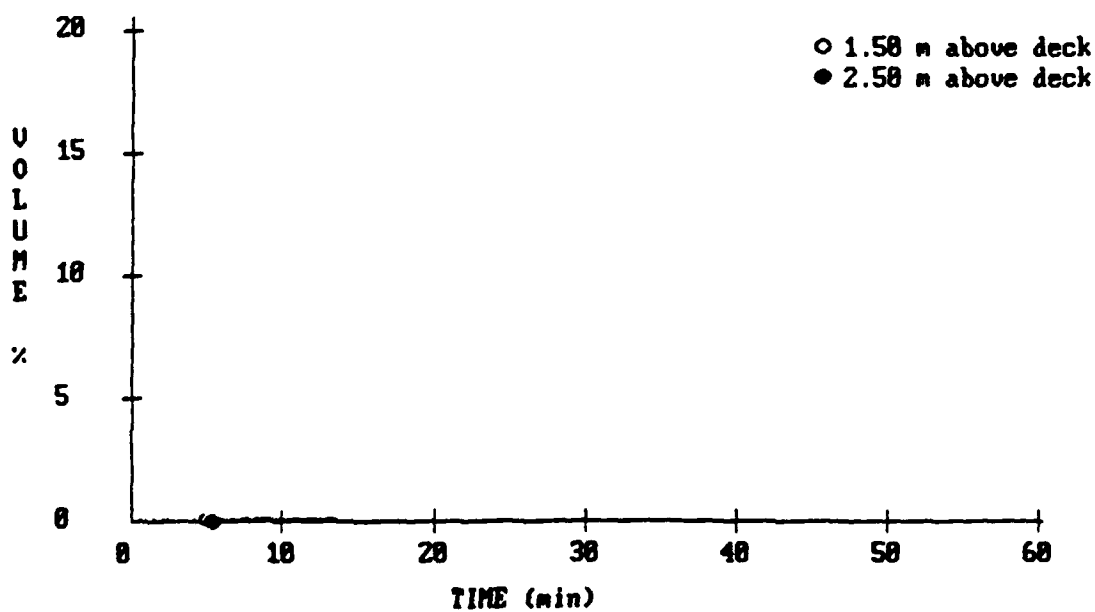


Fig. B-262- CO2 concentration in RICER 1 (2-76-2) during Test # 25

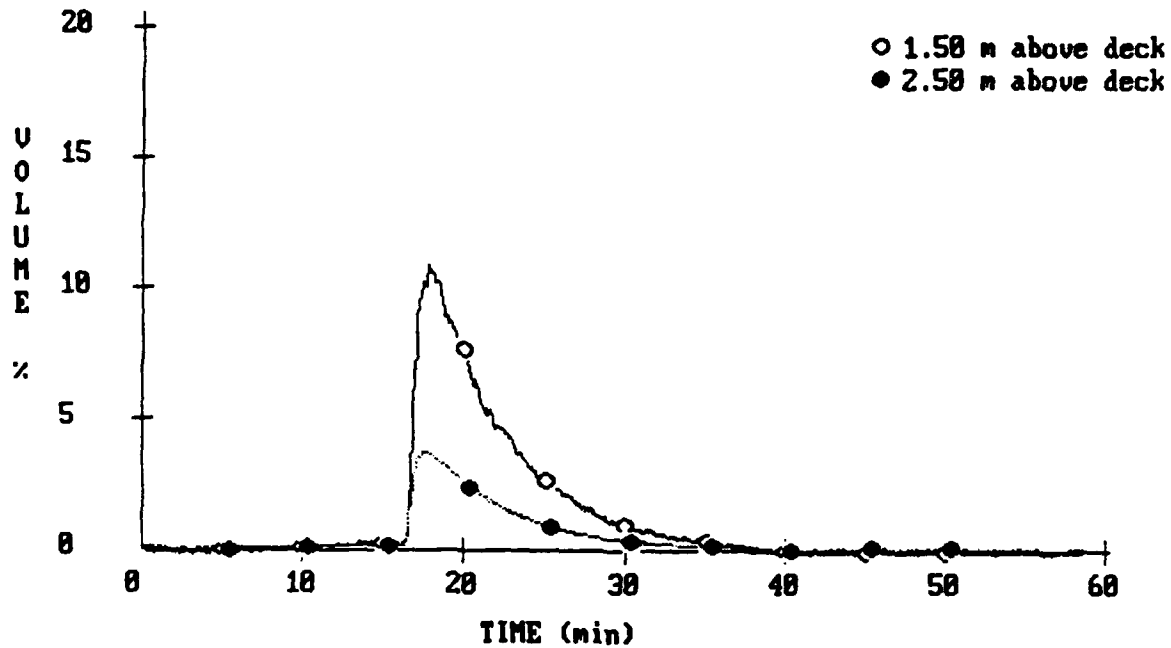


Fig. B-263- CO<sub>2</sub> concentration in RICER 1 (Z-76-2) during Test # 30

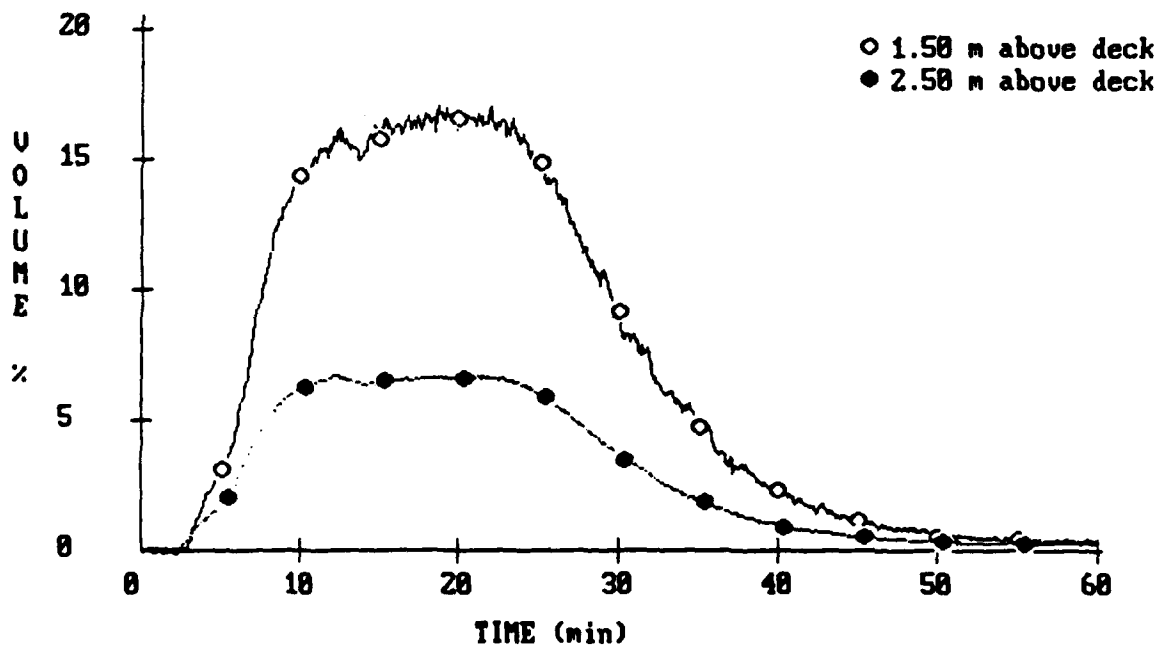


Fig. B-264- CO<sub>2</sub> concentration in RICER 1 (Z-76-2) during Test # 31



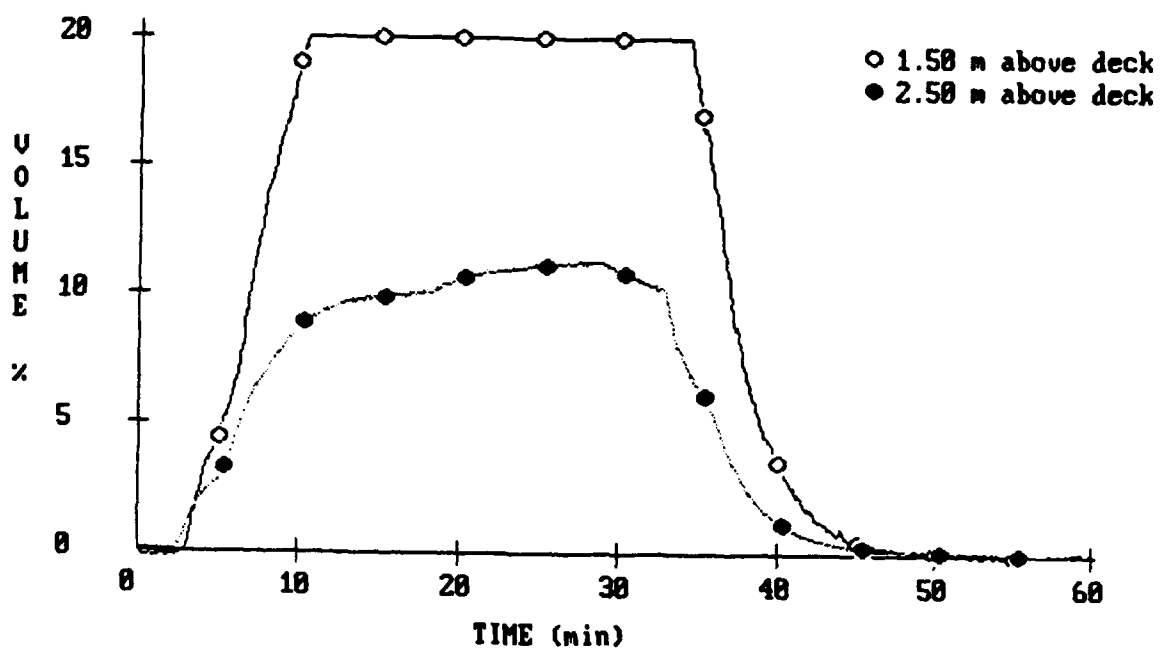


Fig. B-265- CO2 concentration in RICER 1 (2-76-2) during Test # 32

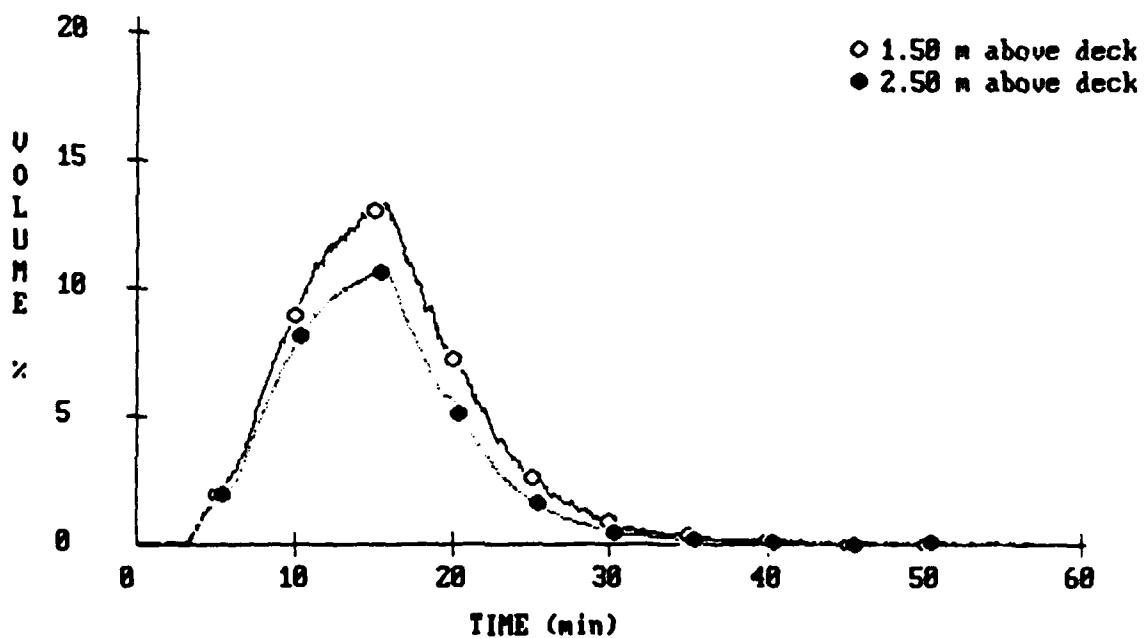


Fig. B-266- CO2 concentration in RICER 1 (2-76-2) during Test # 33

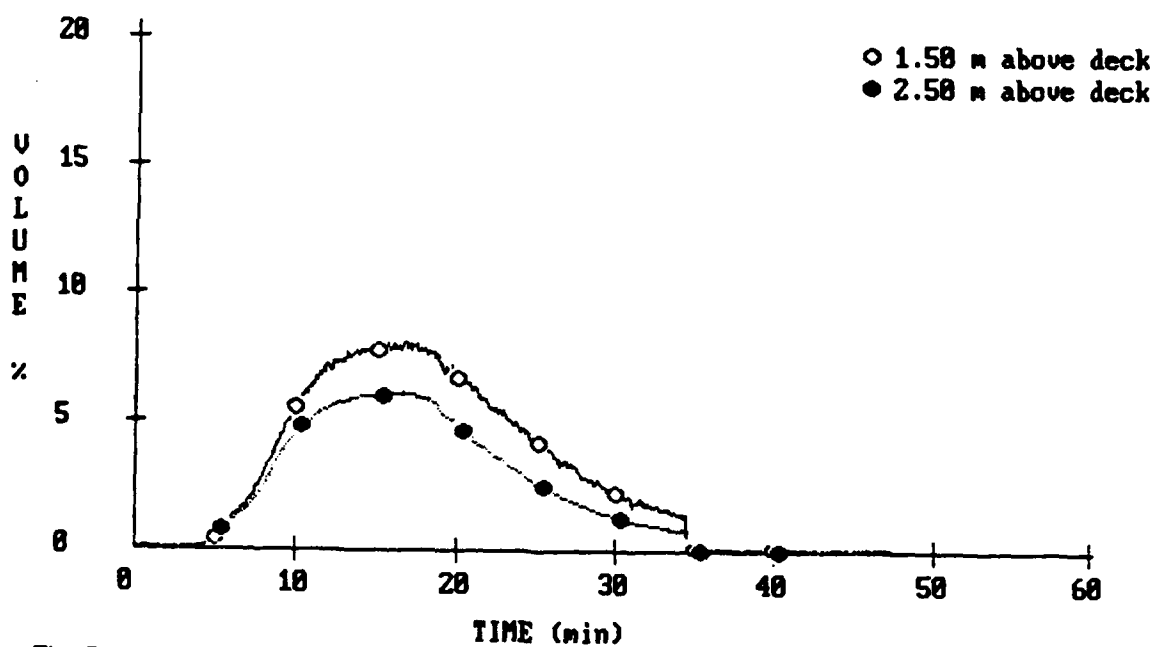


Fig. B-267- CO2 concentration in RICER 1 (2-76-2) during Test # 34

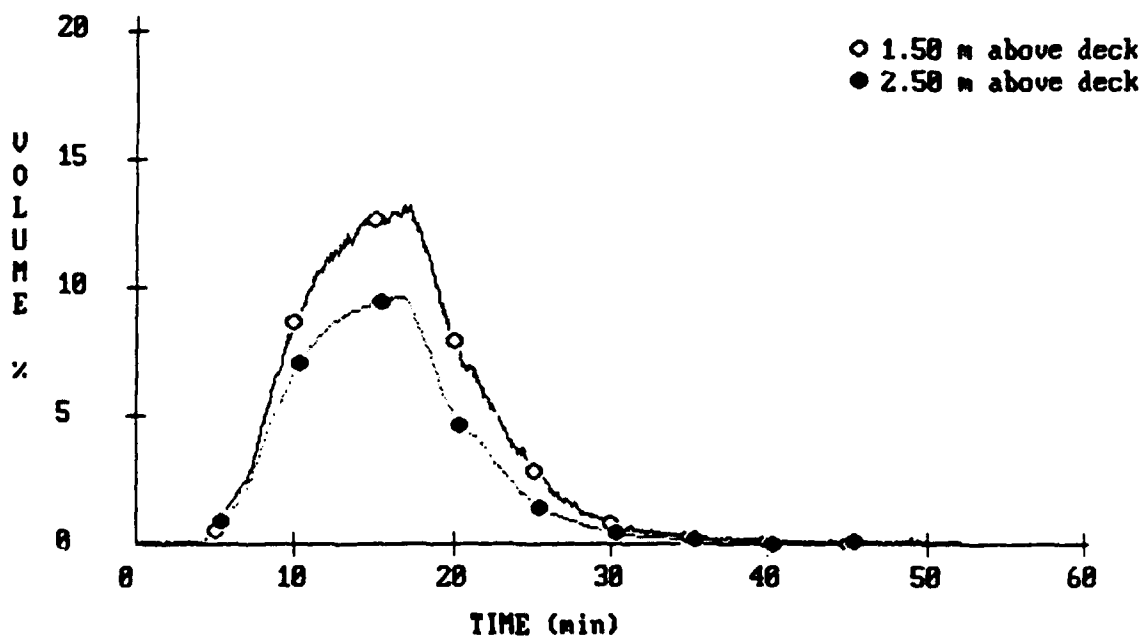


Fig. B-268- CO2 concentration in RICER 1 (2-76-2) during Test # 35

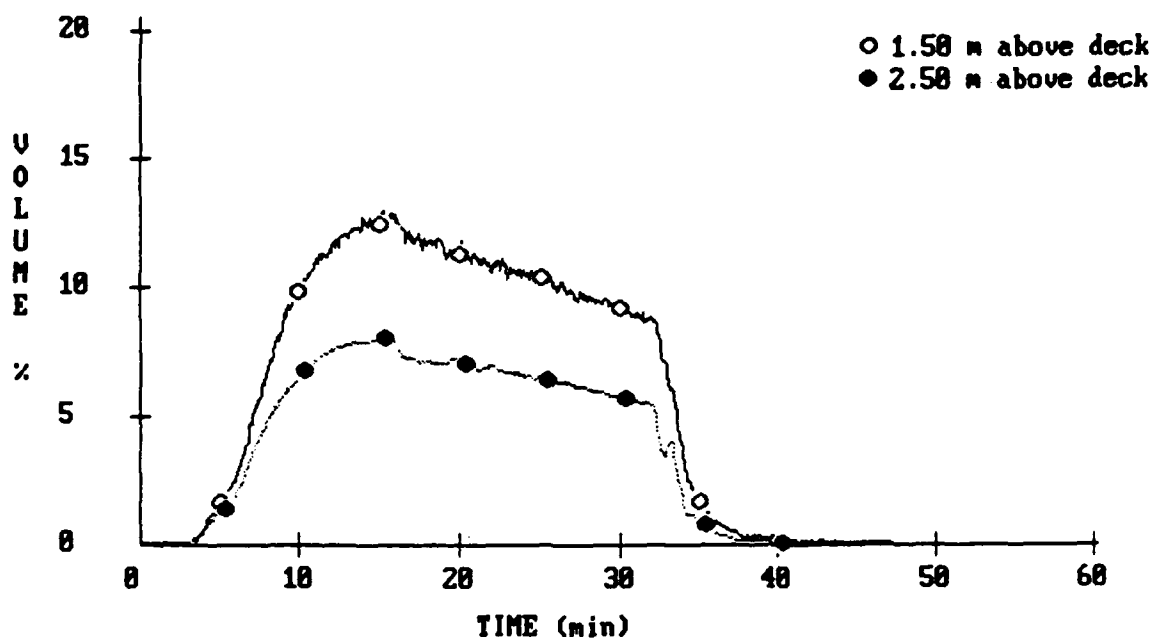


Fig. B-269- CO2 concentration in RICER 1 (2-76-2) during Test # 36

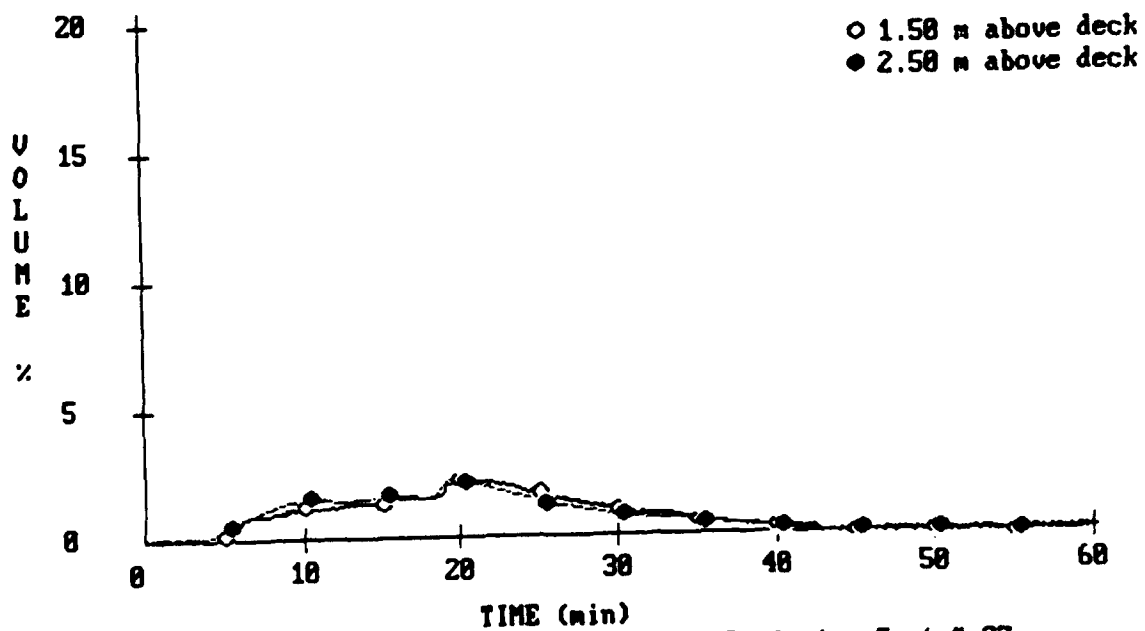


Fig. B-270- CO2 concentration in RICER 1 (2-76-2) during Test # 37

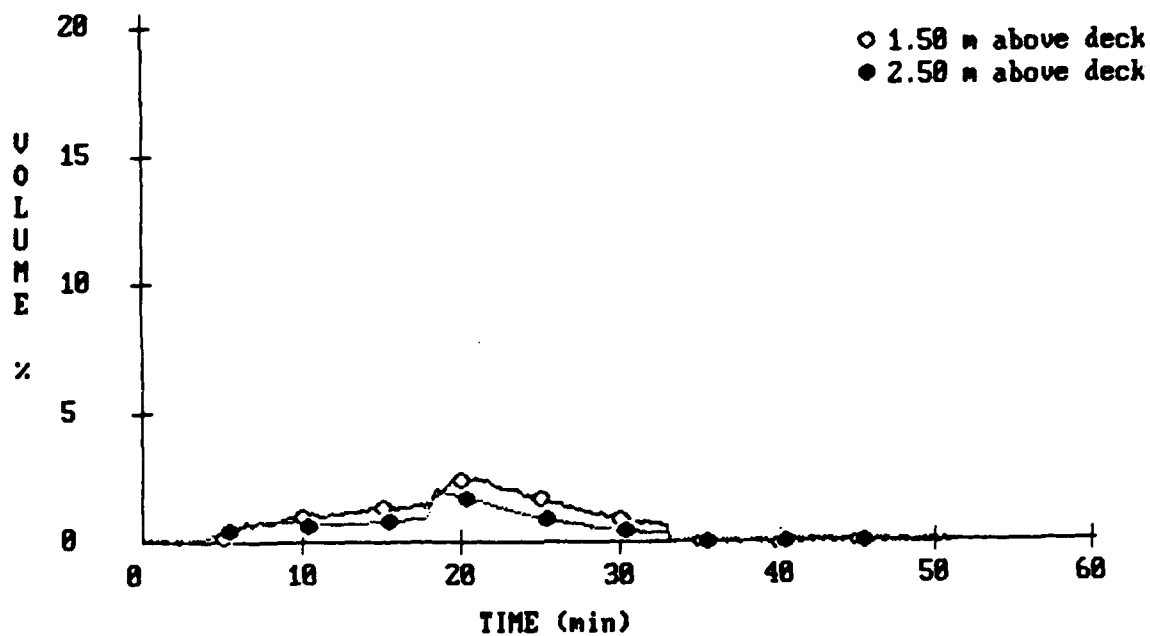


Fig. B-271- CO2 concentration in RICER 1 (2-76-2) during Test # 38

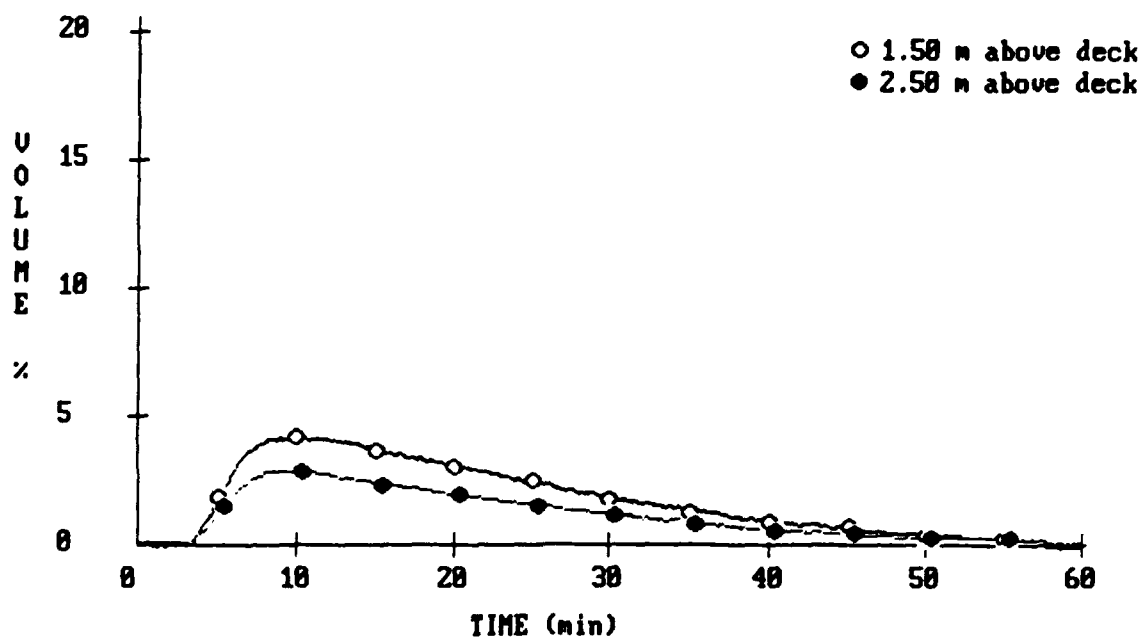


Fig. B-272- CO2 concentration in RICER 1 (2-76-2) during Test # 39

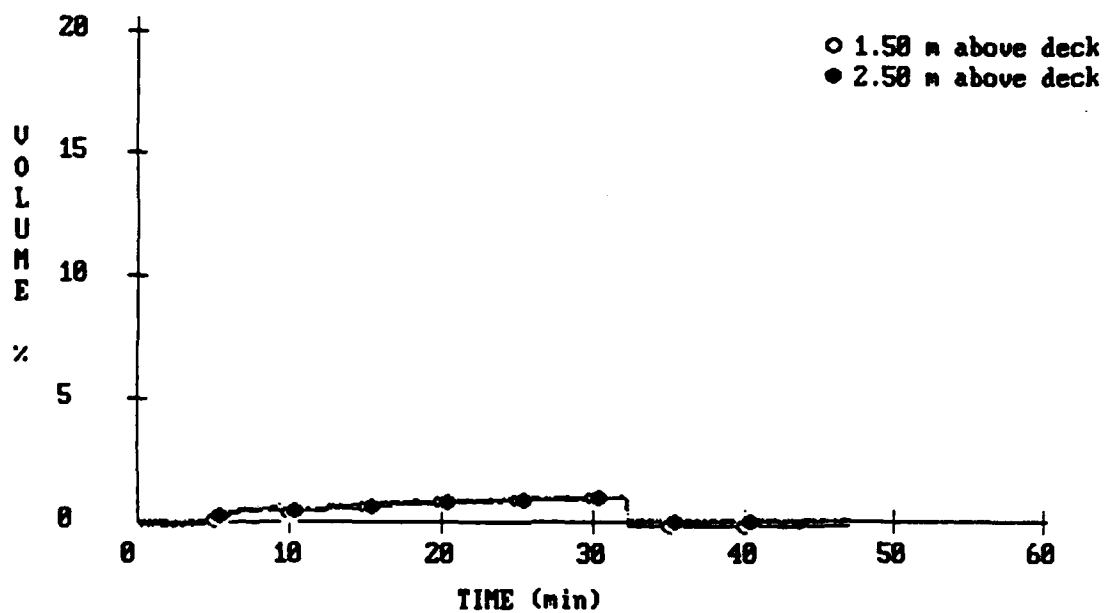


Fig. B-273- CO2 concentration in RICER 1 (2-76-2) during Test # 48

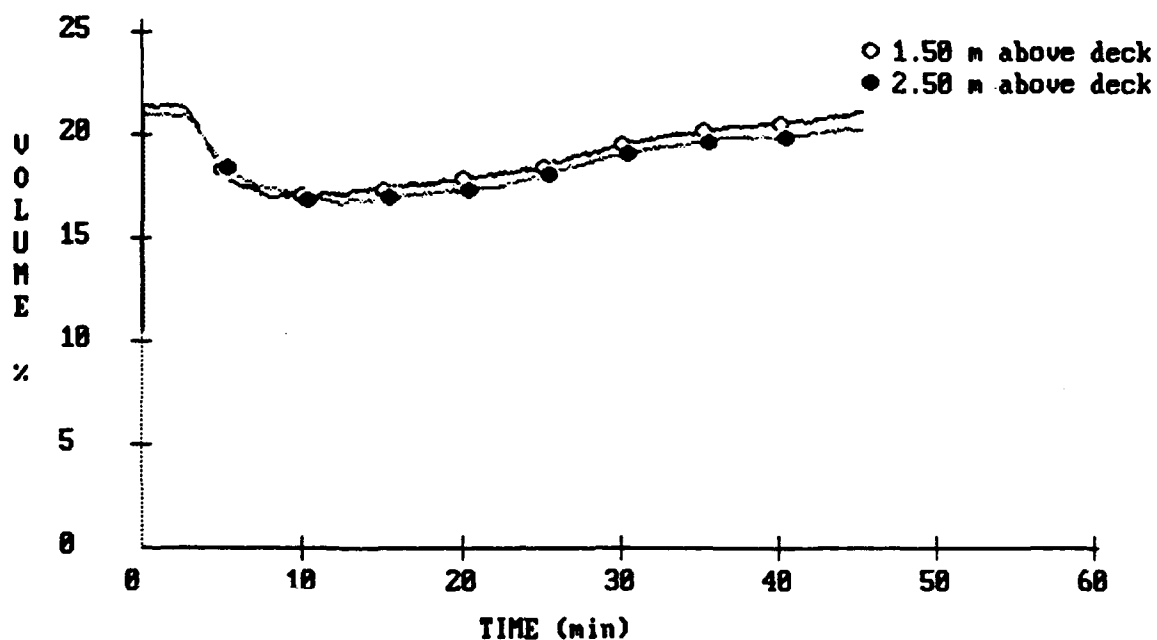


Fig. B-274- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 2

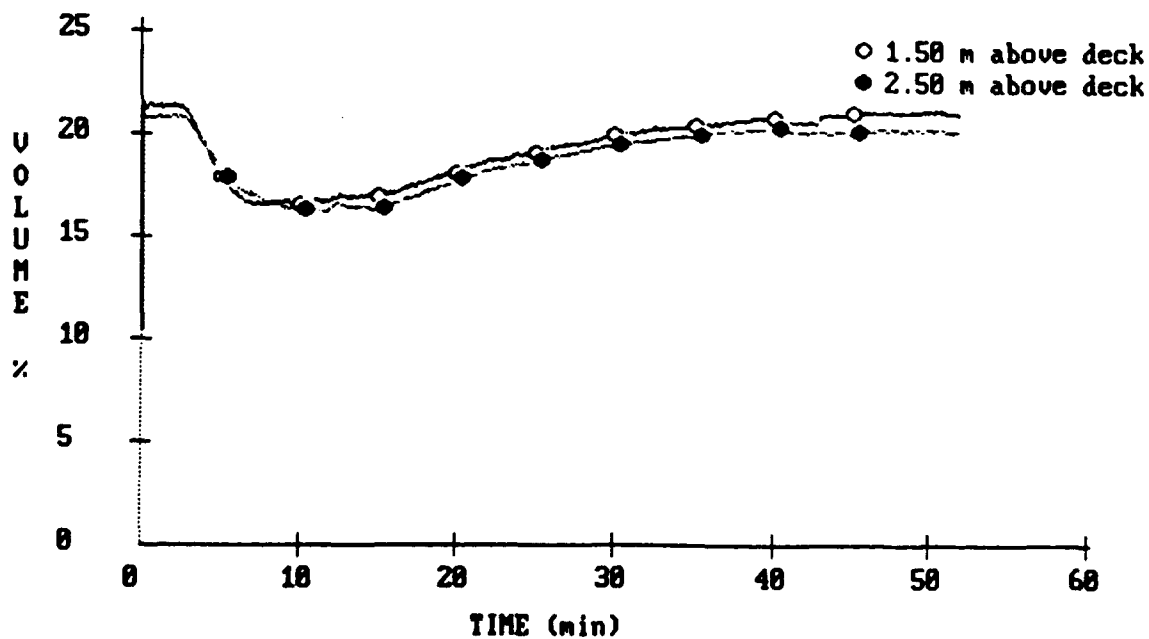


Fig. B-275- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 3

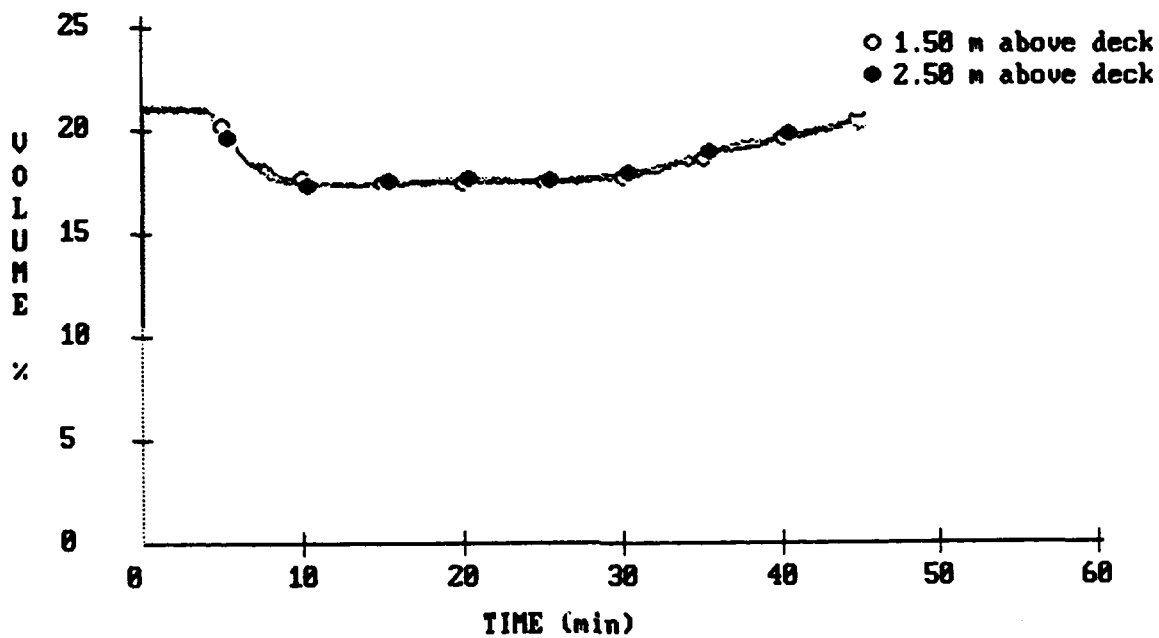


Fig. B-276-02 concentration in RICER 1 (2-76-2) during Test # 4

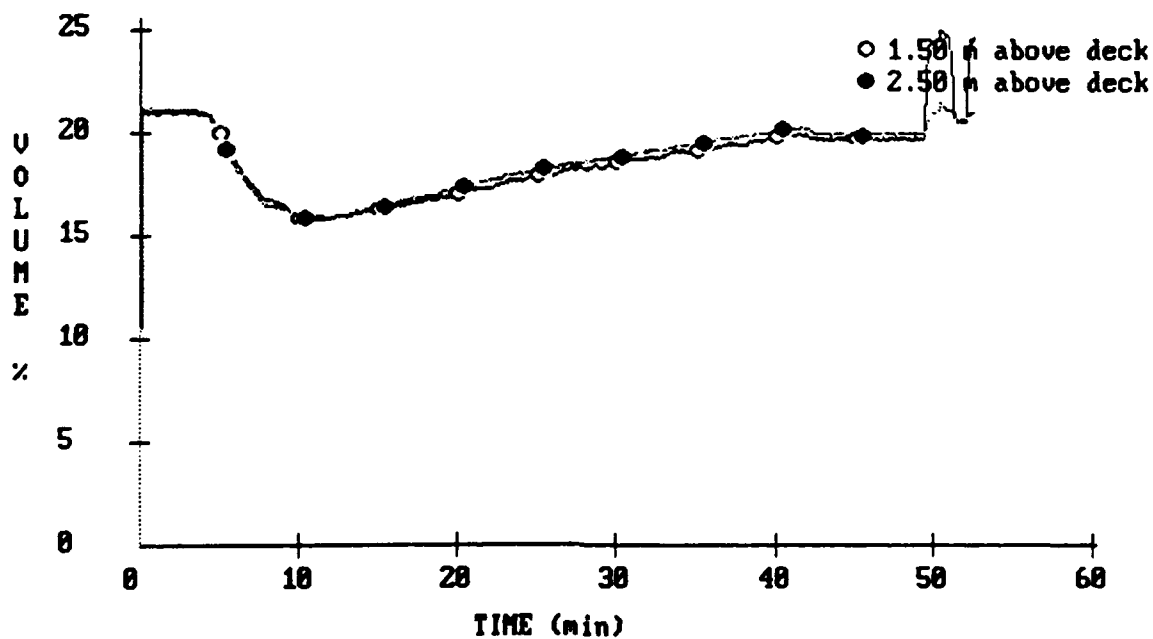


Fig. B-277-02 concentration in RICER 1 (2-76-2) during Test # 5

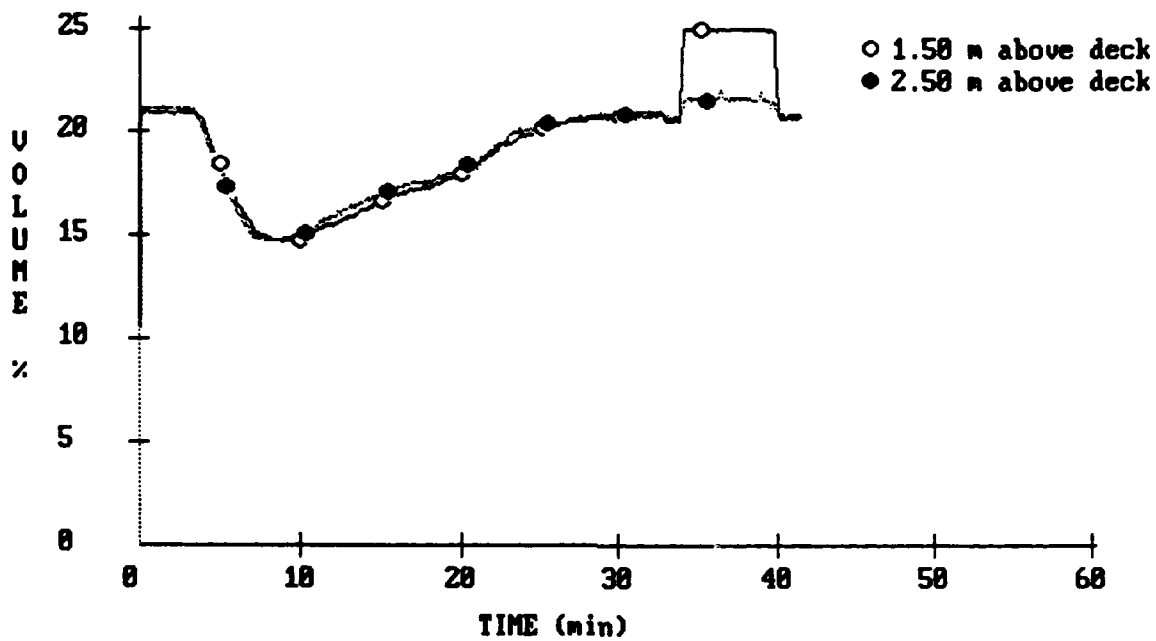


Fig. B-278-02 concentration in RICER 1 (2-76-2) during Test # 6

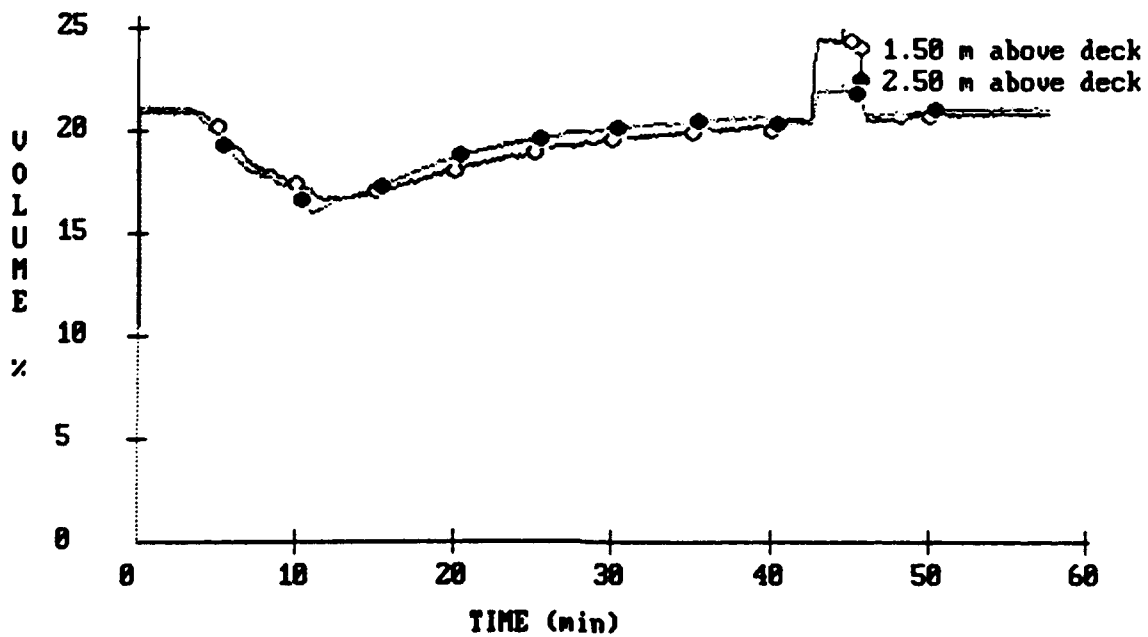


Fig. B-279-02 concentration in RICER 1 (2-76-2) during Test # 7



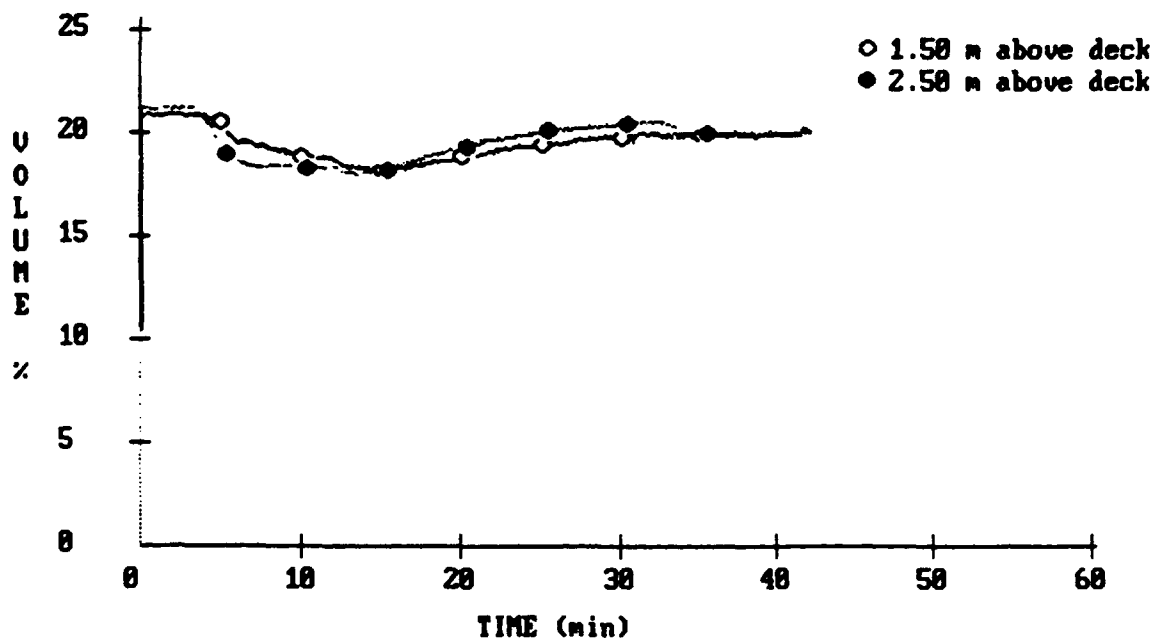


Fig. B-280- O2 concentration in RICER 1 (2-76-2) during Test # 8

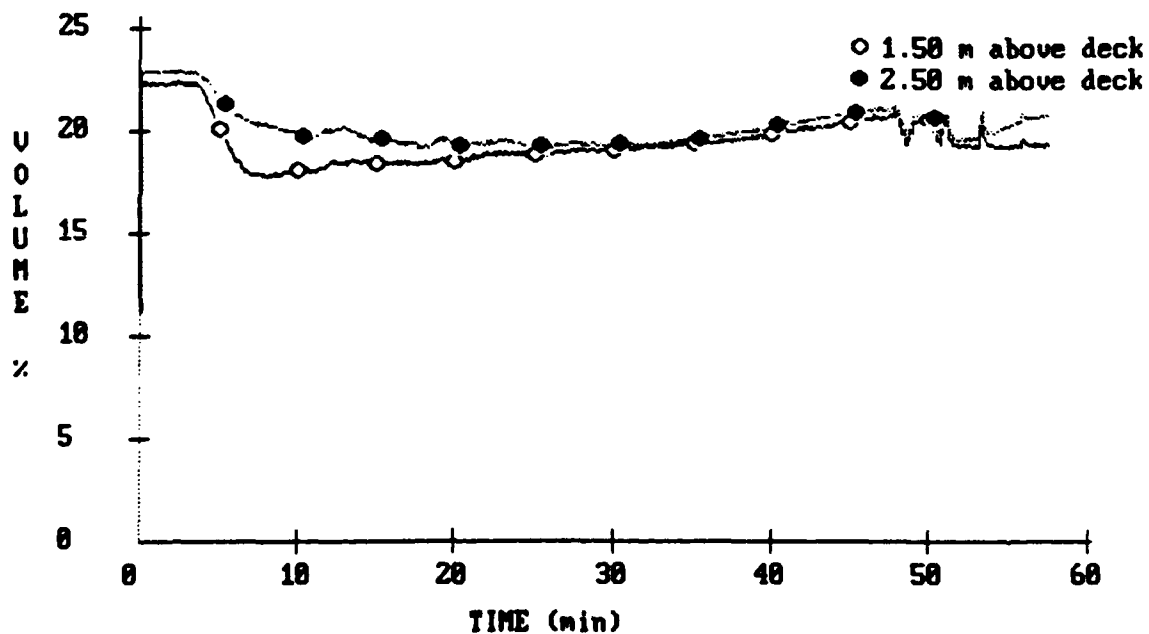


Fig. B-281- O2 concentration in RICER 1 (2-76-2) during Test # 9

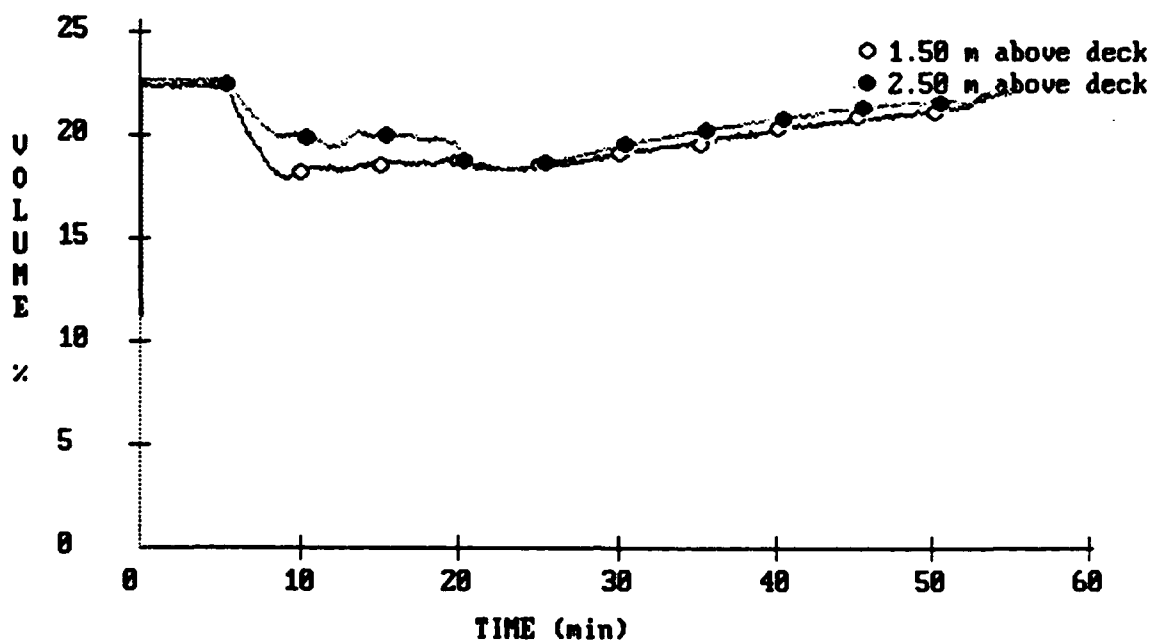


Fig. B-282- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 10

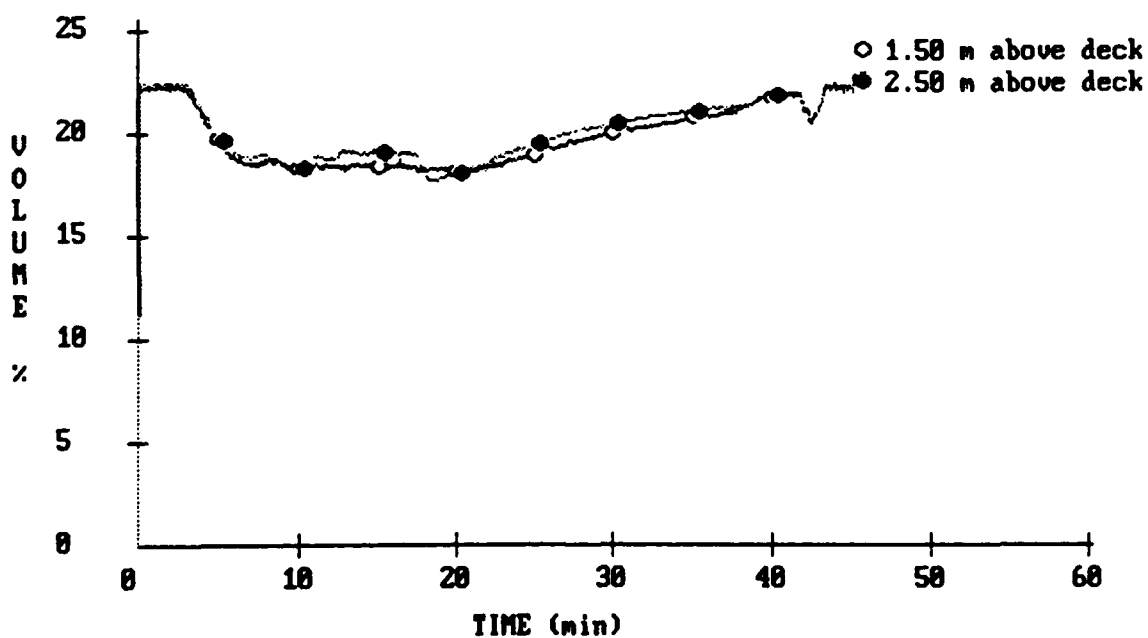


Fig. B-283- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 11

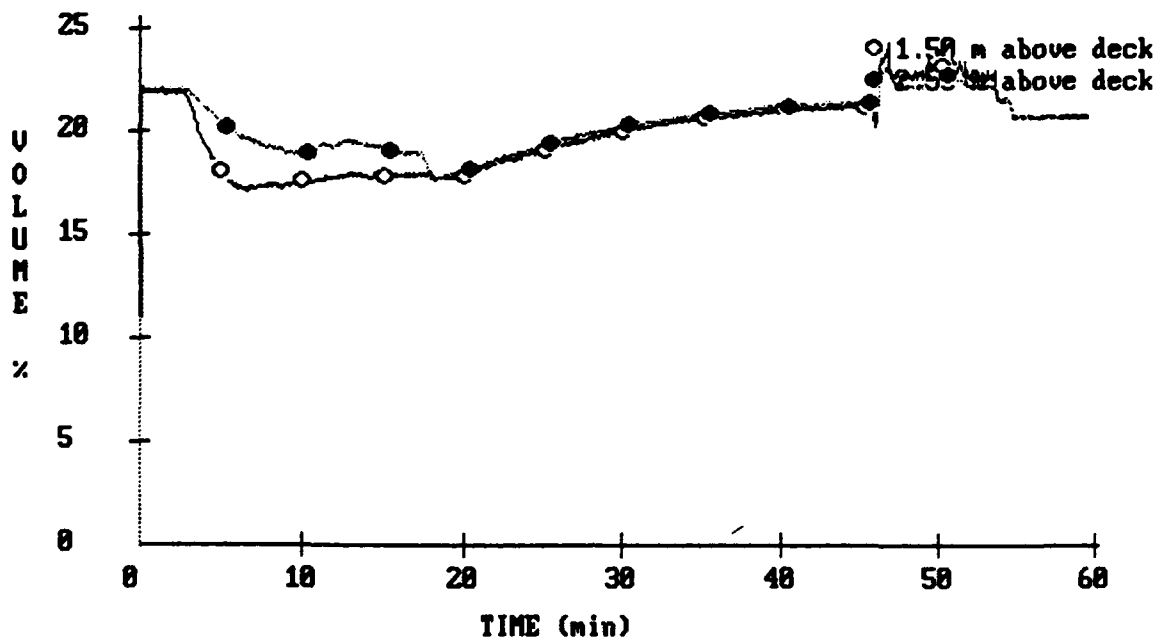


Fig. B-284- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 12

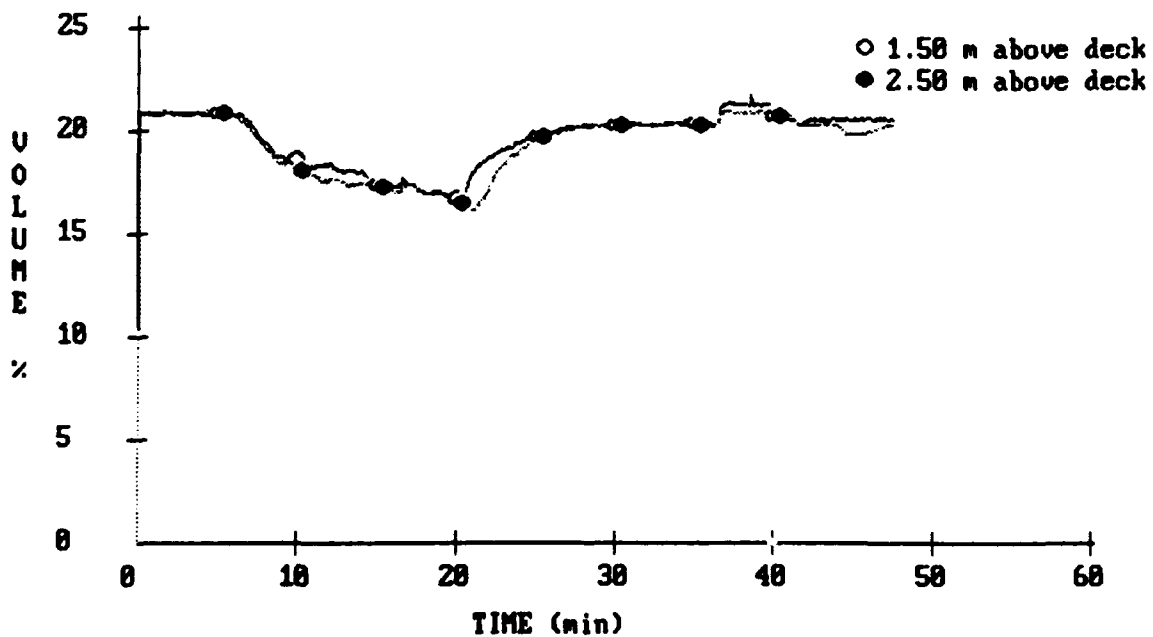


Fig. B-285- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 13

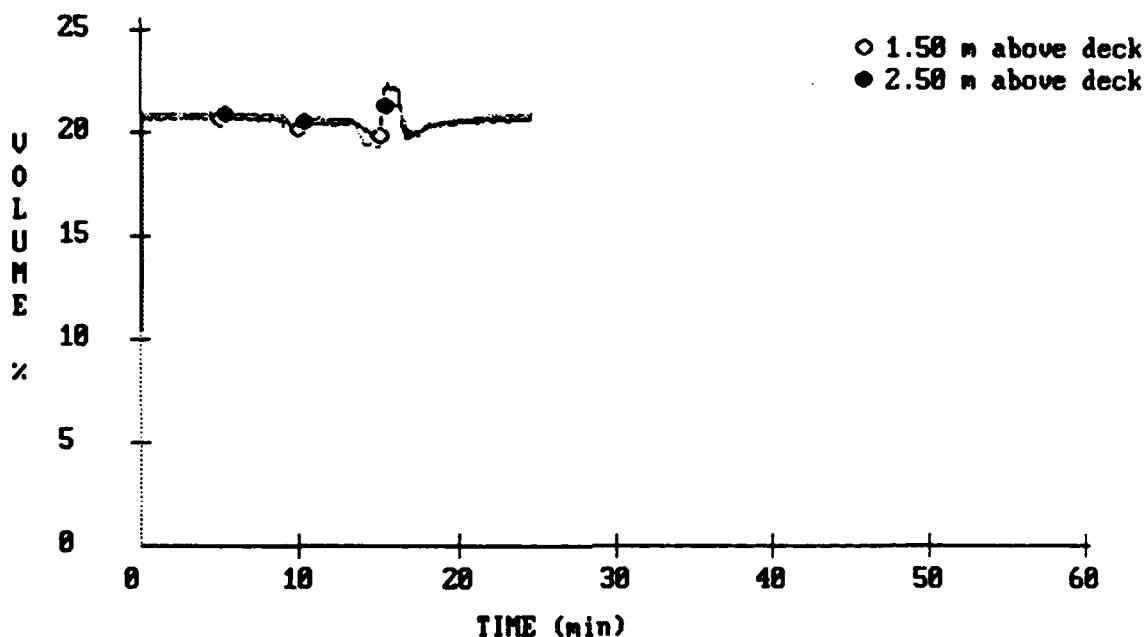


Fig. B-286- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 14

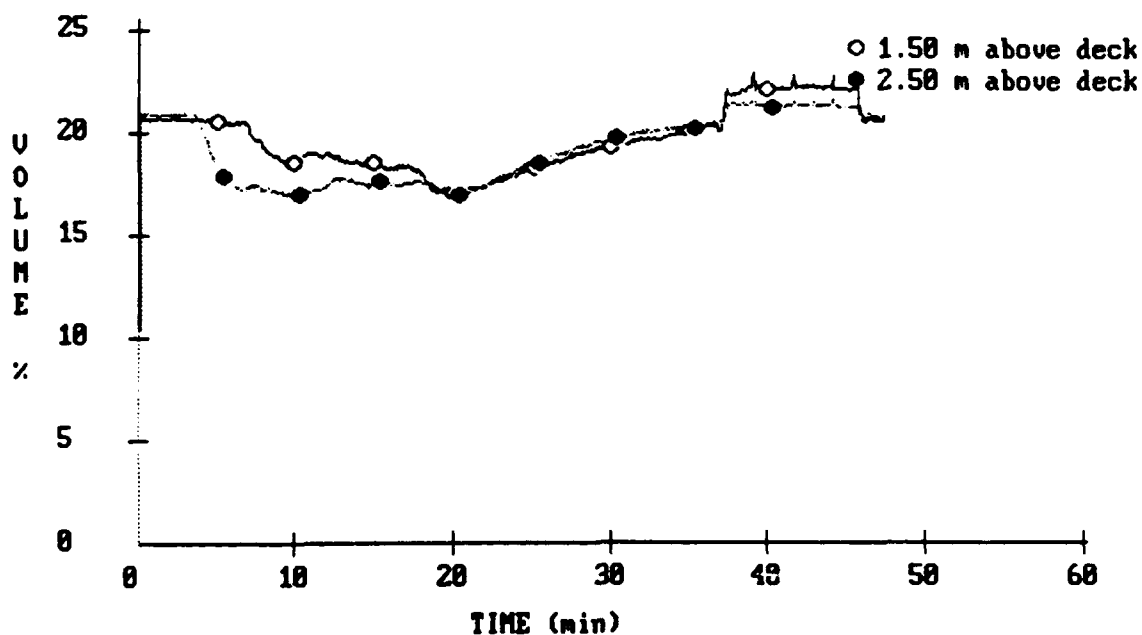


Fig. B-287- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 15

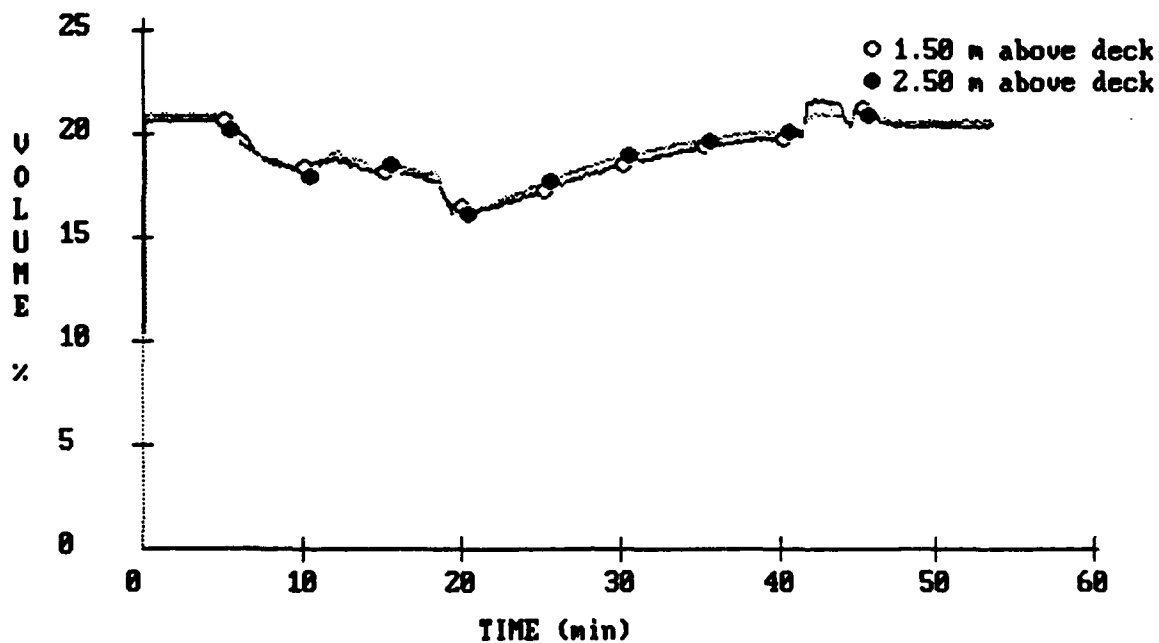


Fig. B-288- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 16

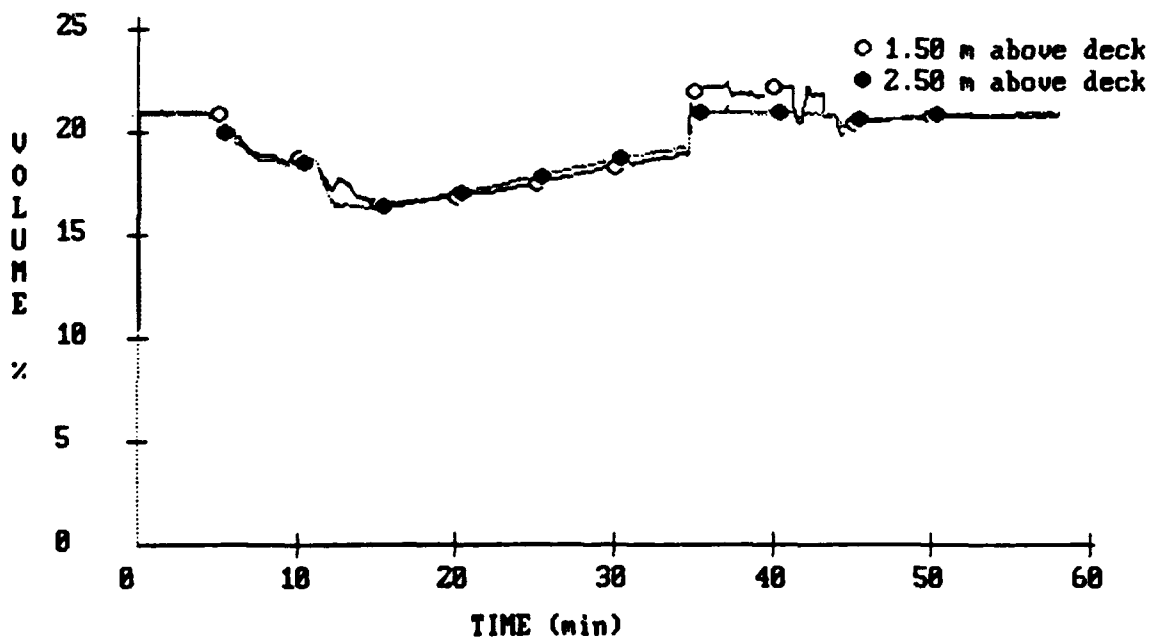


Fig. B-289- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 17

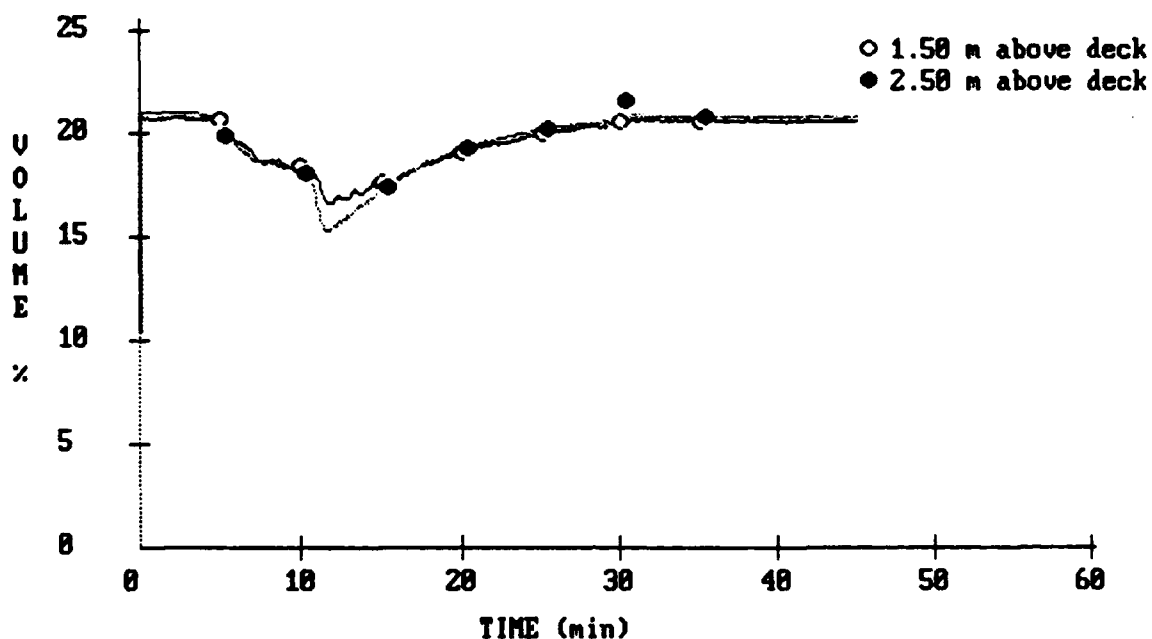


Fig. B-290- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 18

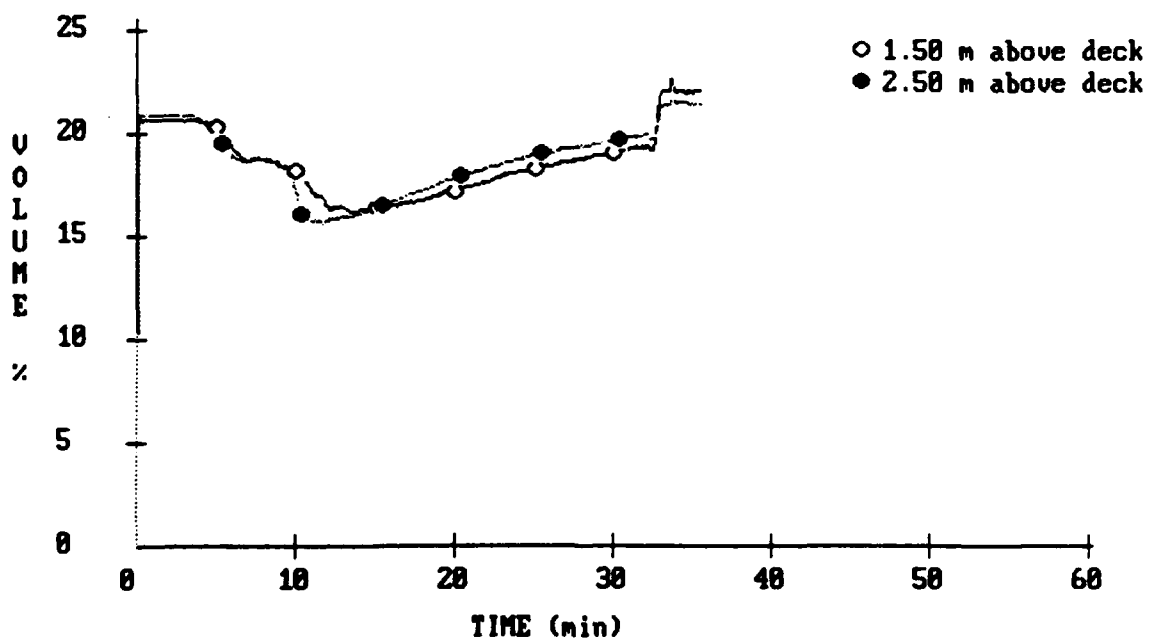


Fig. B-291- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 19

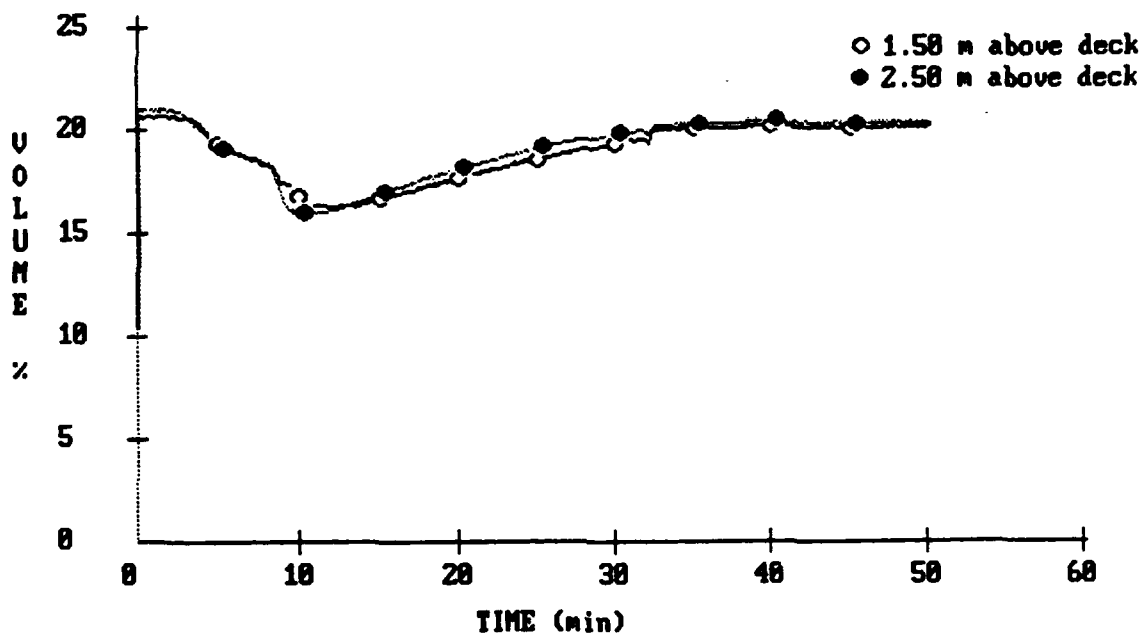


Fig. B-292- O2 concentration in RICER 1 (2-76-2) during Test # 20

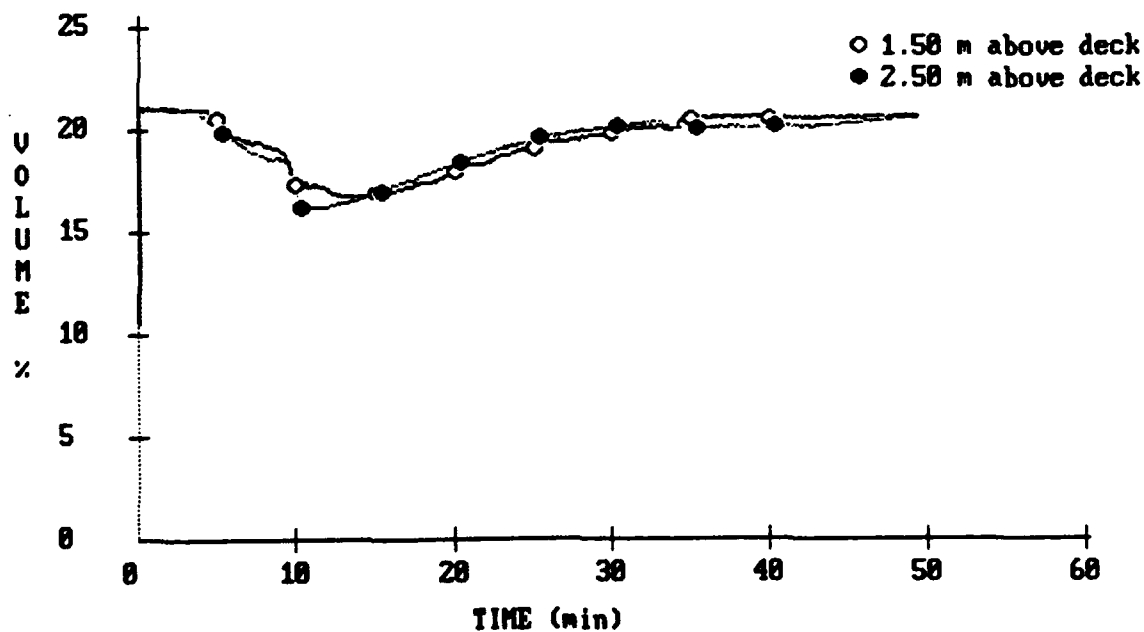


Fig. B-293- O2 concentration in RICER 1 (2-76-2) during Test # 21

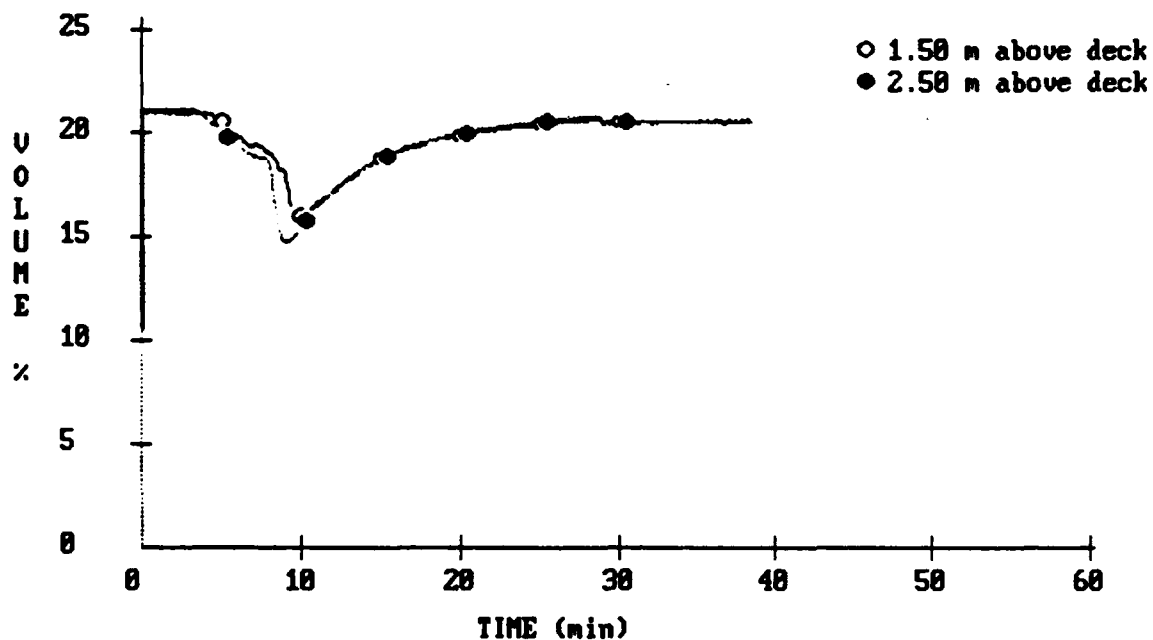


Fig. B-294-02 concentration in RICER 1 (2-76-2) during Test # 22

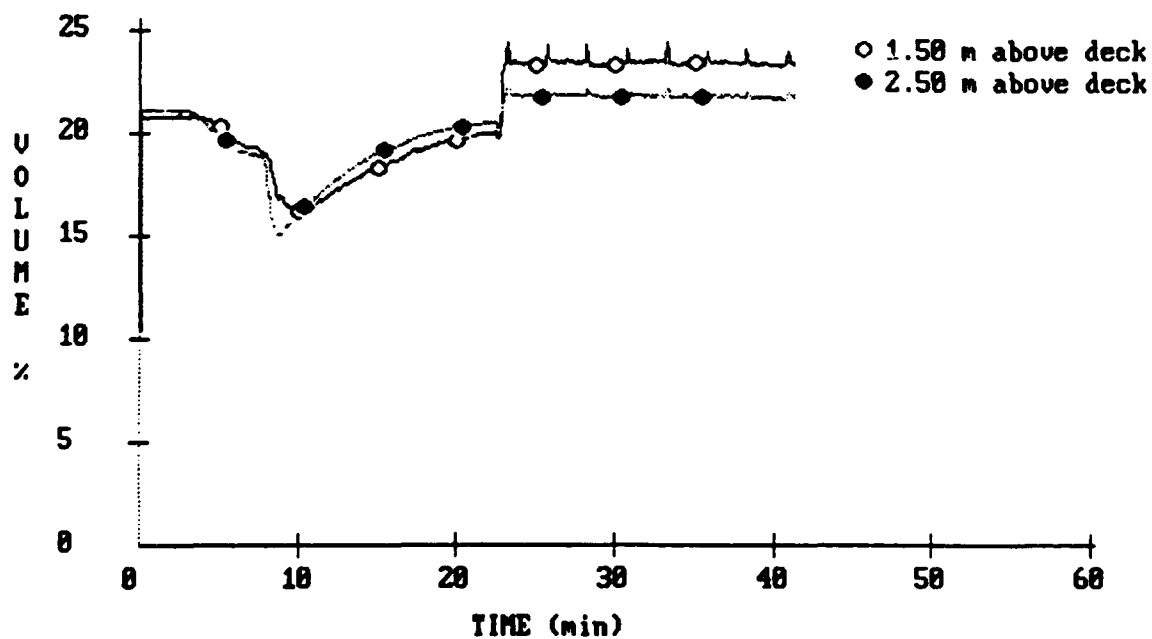


Fig. B-295-02 concentration in RICER 1 (2-76-2) during Test # 23



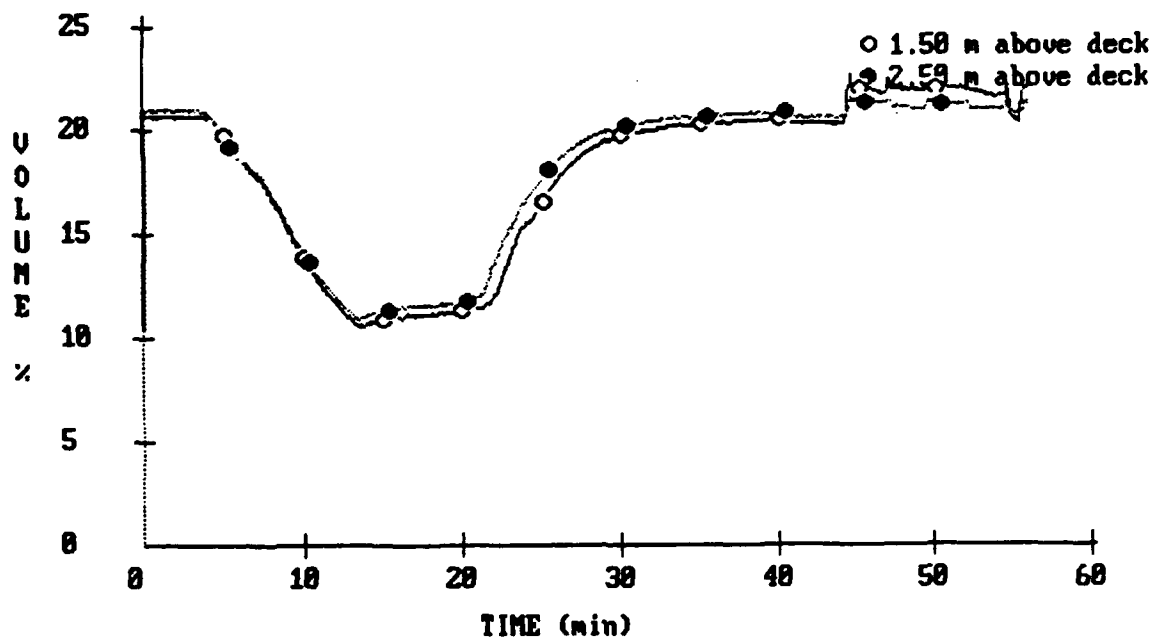


Fig. B-296- O2 concentration in RICER 1 (2-76-2) during Test # 24

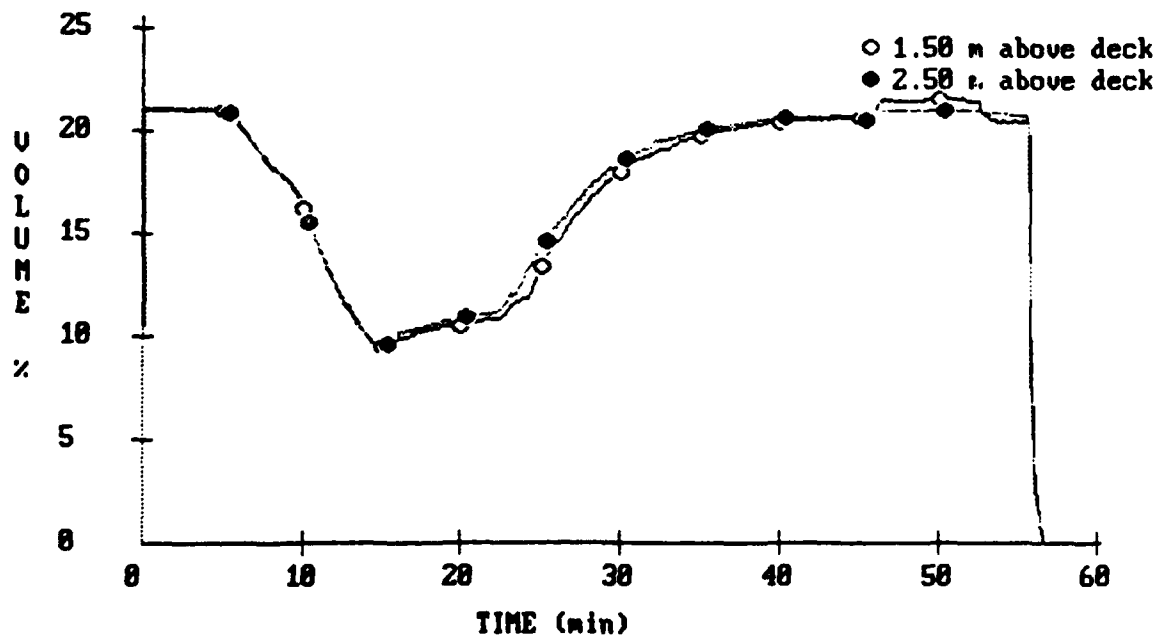


Fig. B-297- O2 concentration in RICER 1 (2-76-2) during Test # 25

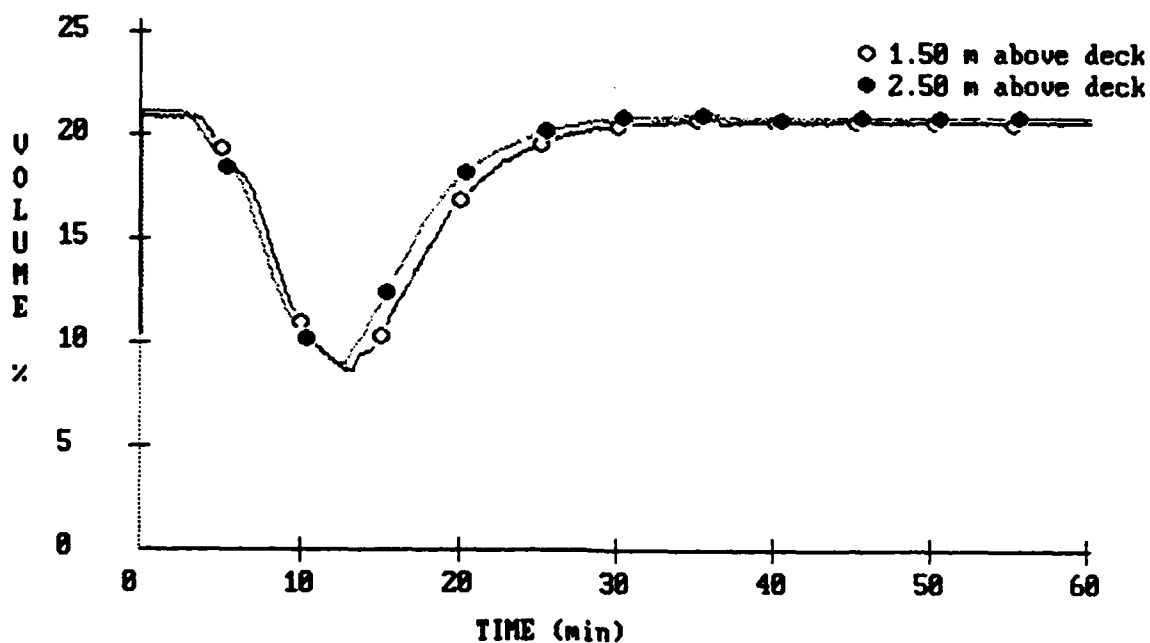


Fig. B-298-O2 concentration in RICER 1 (2-76-2) during Test # 26

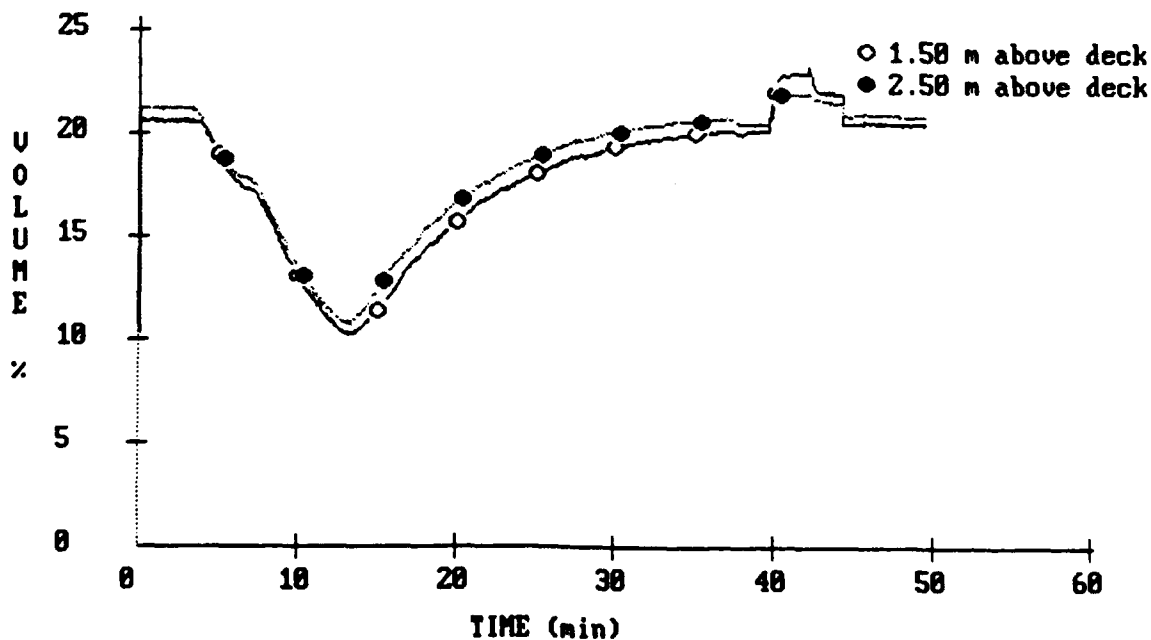


Fig. B-299-O2 concentration in RICER 1 (2-76-2) during Test # 27

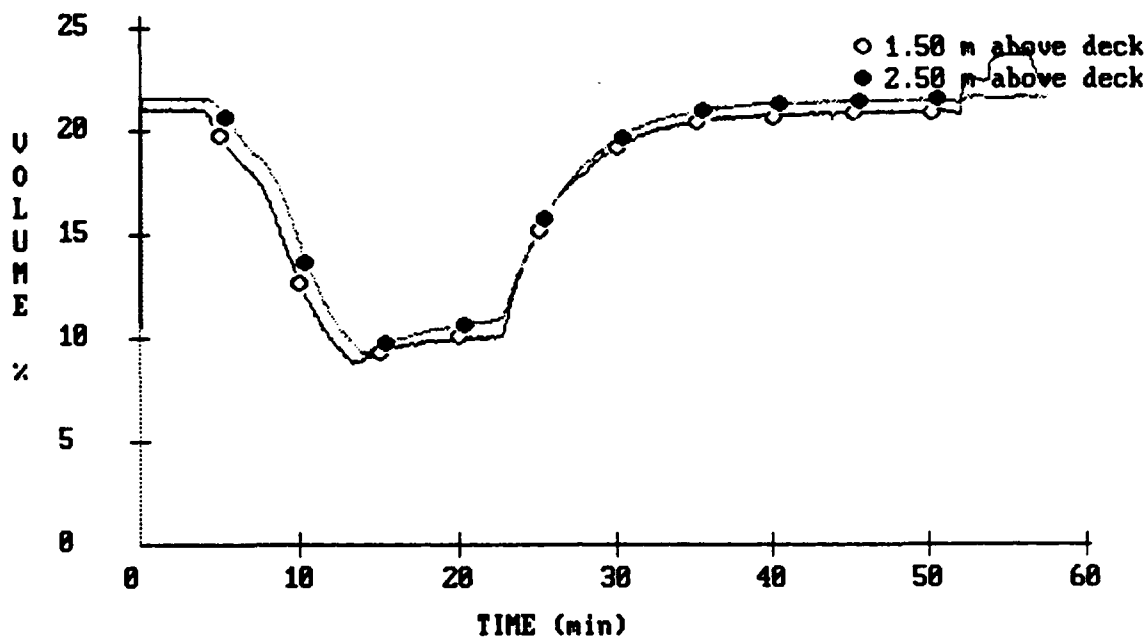


Fig. B-300- 02 concentration in RICER 1 (2-76-2) during Test # 28

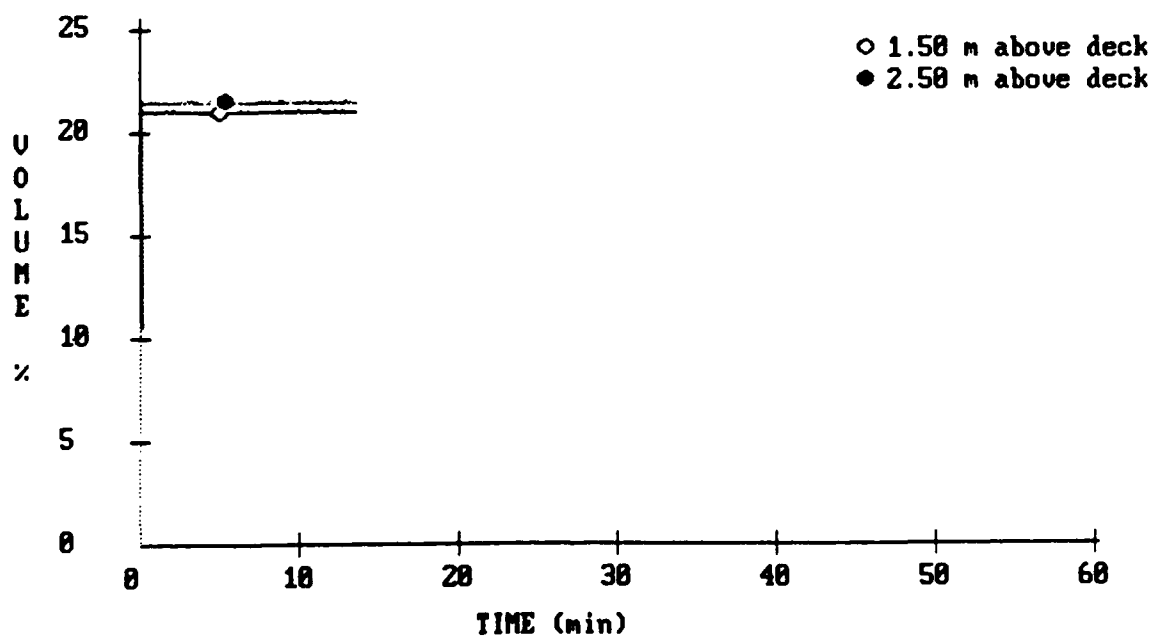


Fig. B-301- 02 concentration in RICER 1 (2-76-2) during Test # 29

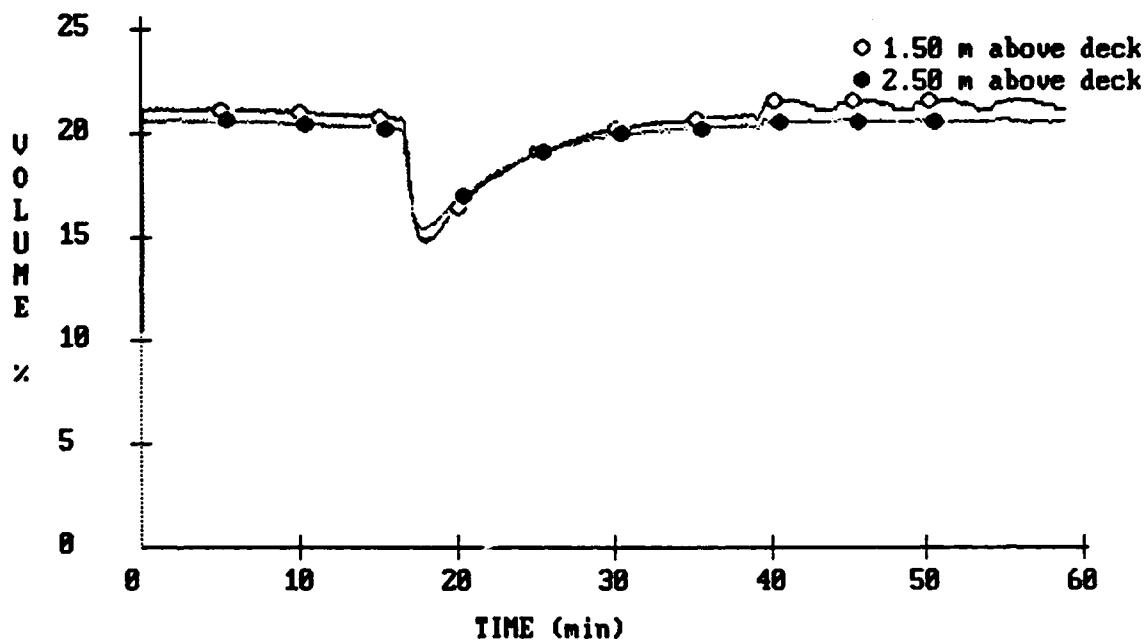


Fig. B-302- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 30

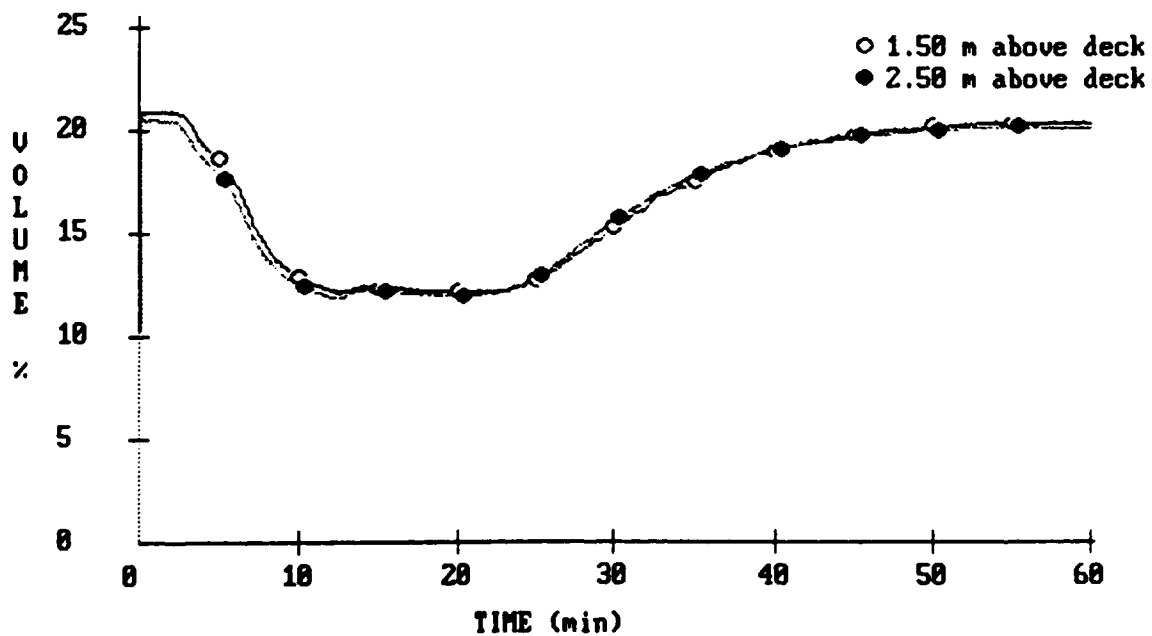


Fig. B-303- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 31

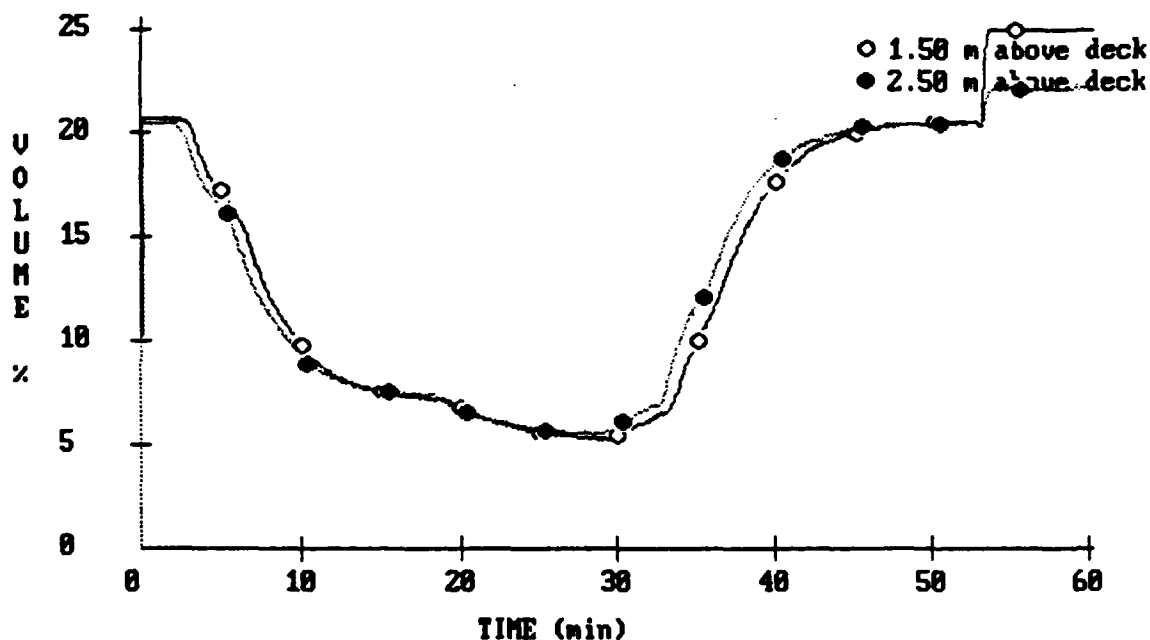


Fig. B-304- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 32

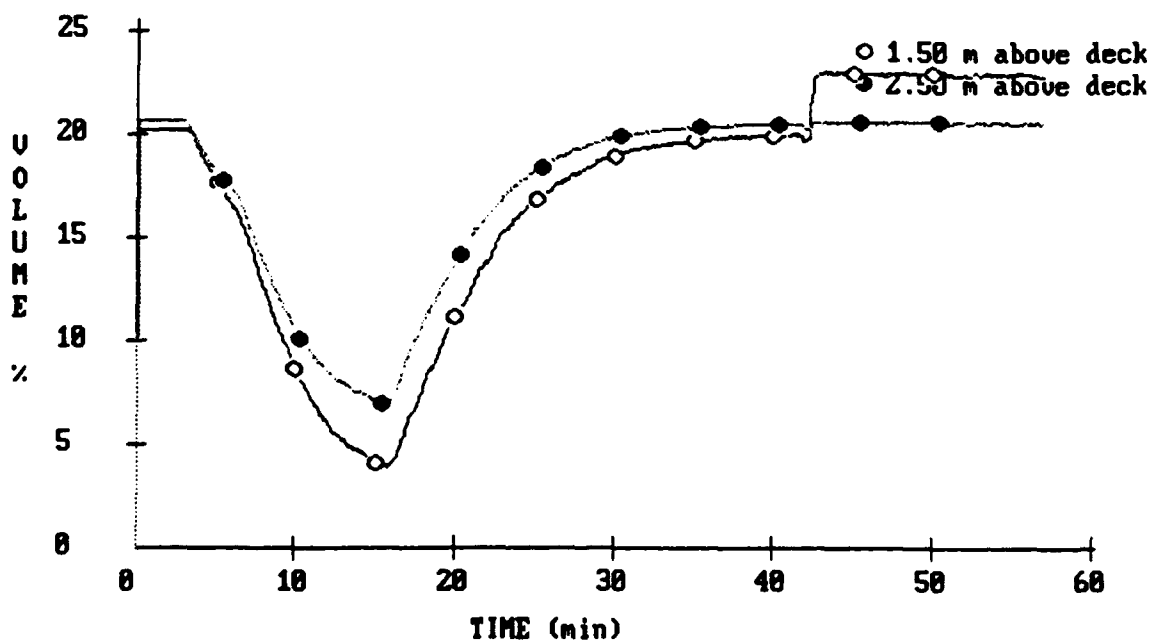


Fig. B-305- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 33

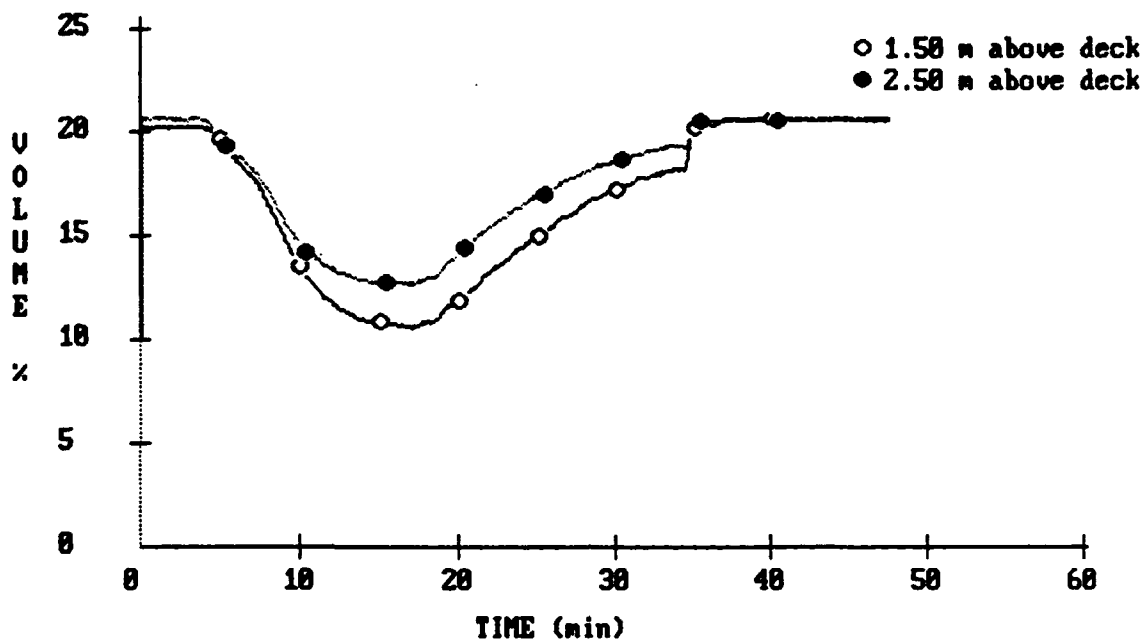


Fig. B-306- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 34

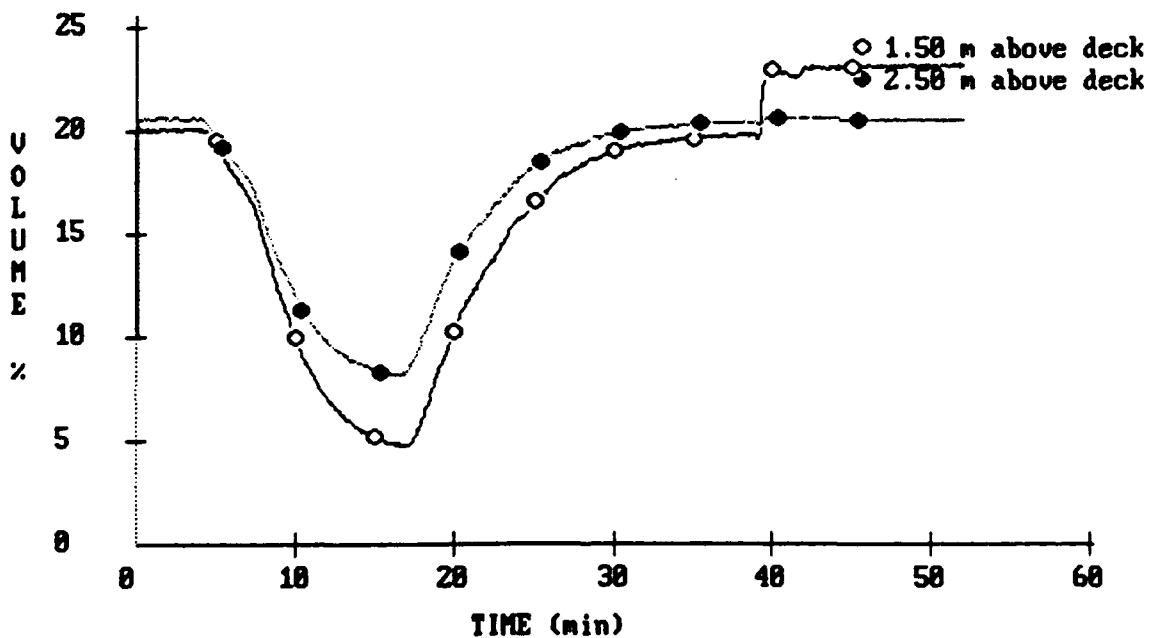


Fig. B-307- O<sub>2</sub> concentration in RICER 1 (2-76-2) during Test # 35

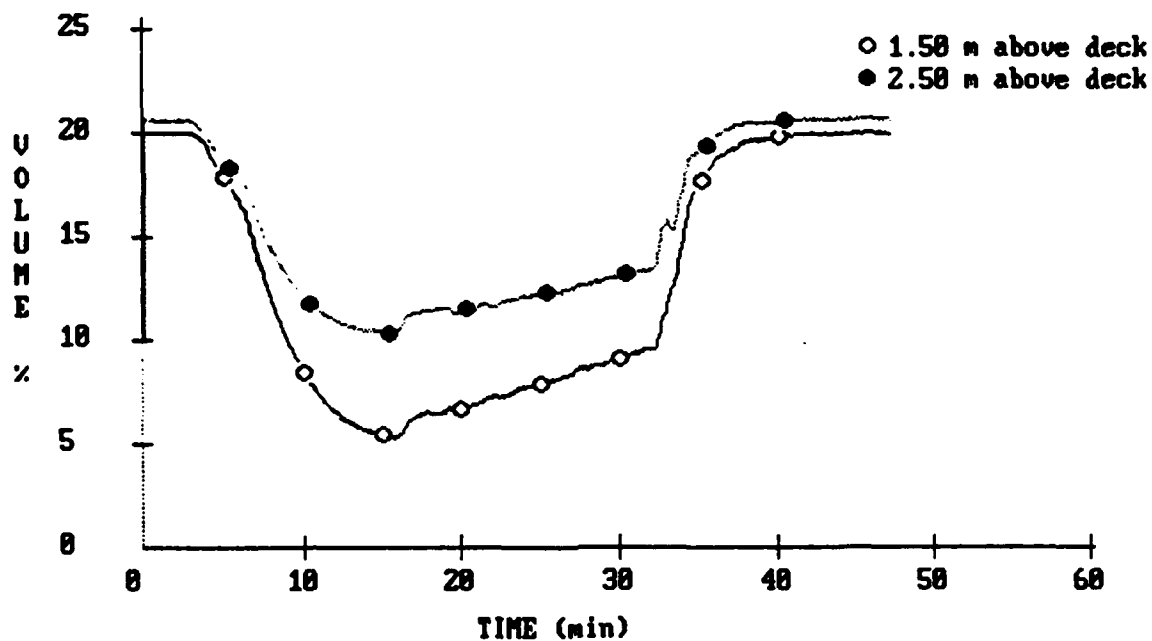


Fig. B-308-02 concentration in RICER 1 (2-76-2) during Test # 36

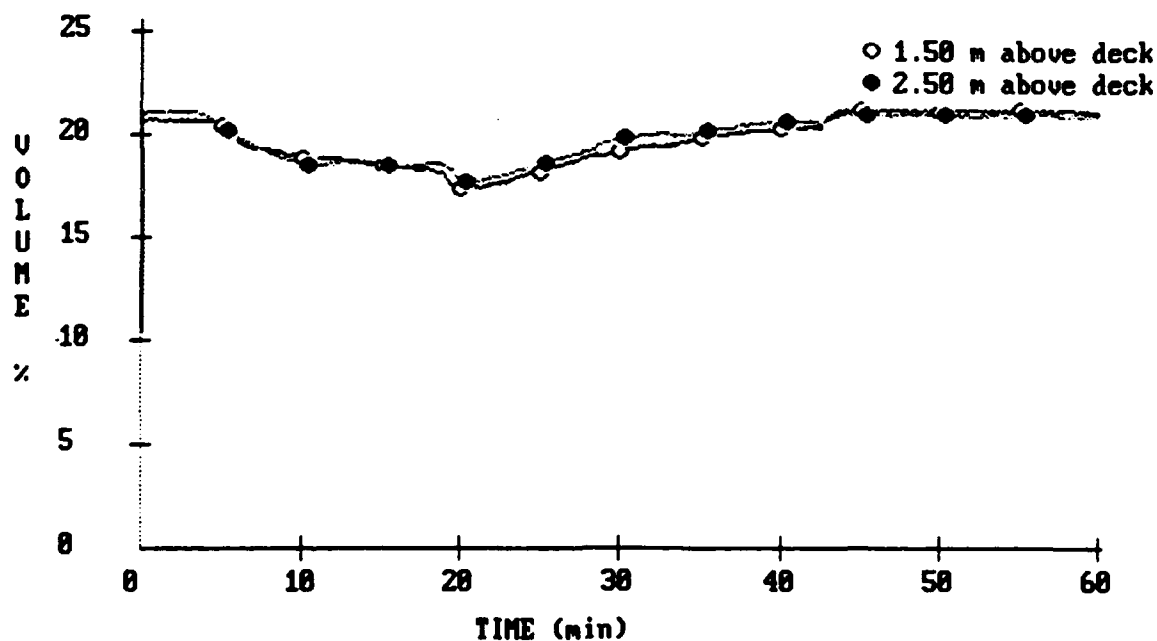


Fig. B-309-02 concentration in RICER 1 (2-76-2) during Test # 37

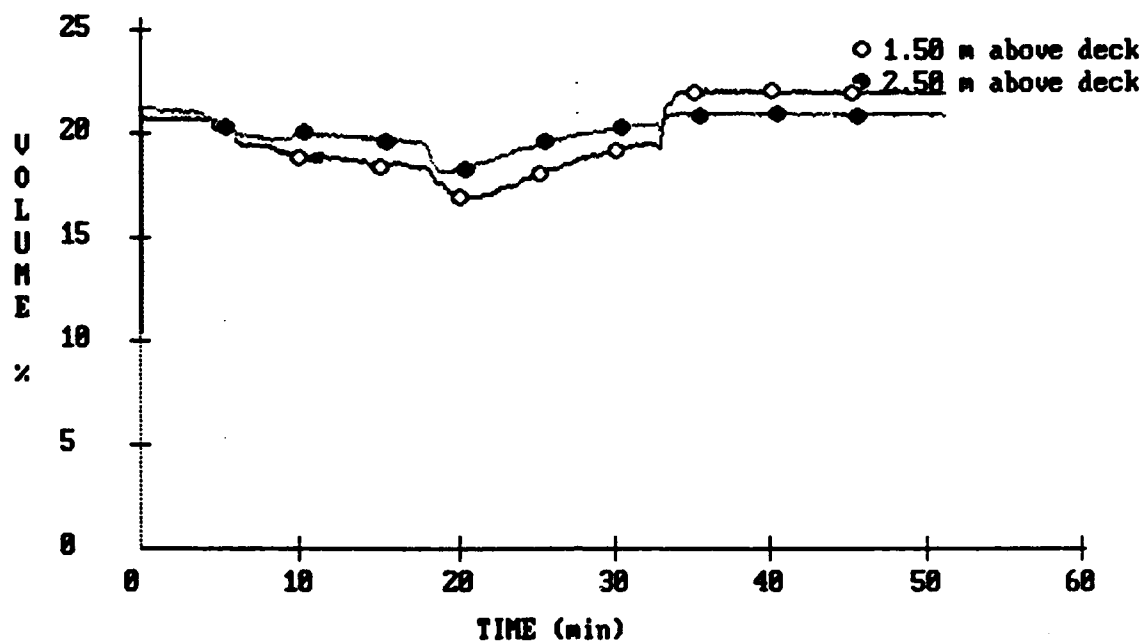


Fig. B-310-02 concentration in RICER 1 (2-76-2) during Test # 38

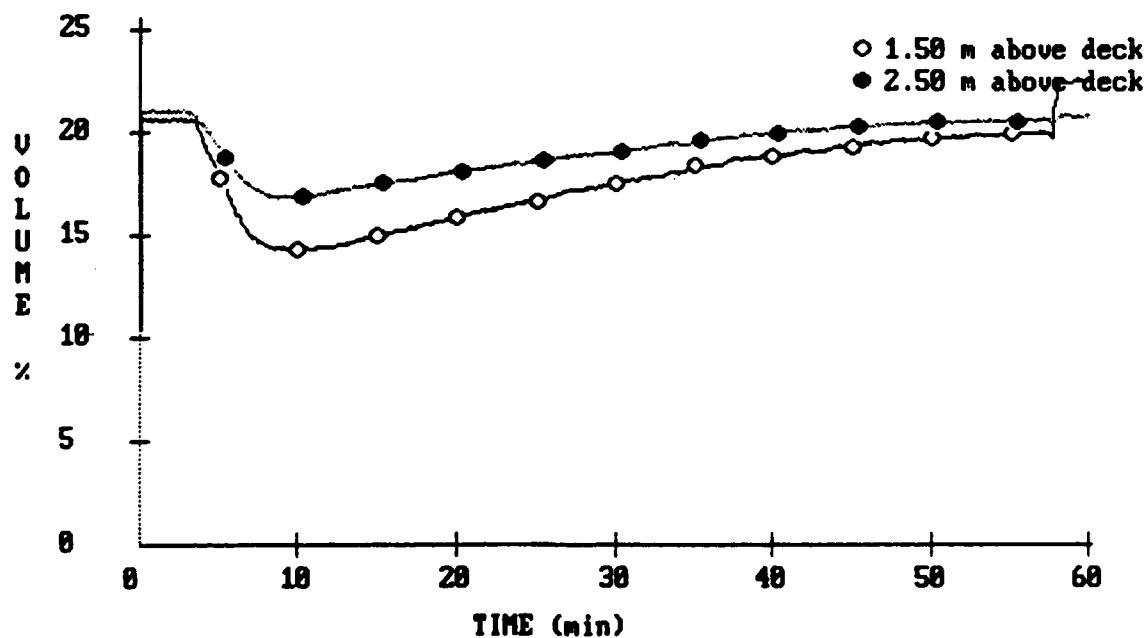


Fig. B-311-02 concentration in RICER 1 (2-76-2) during Test # 39



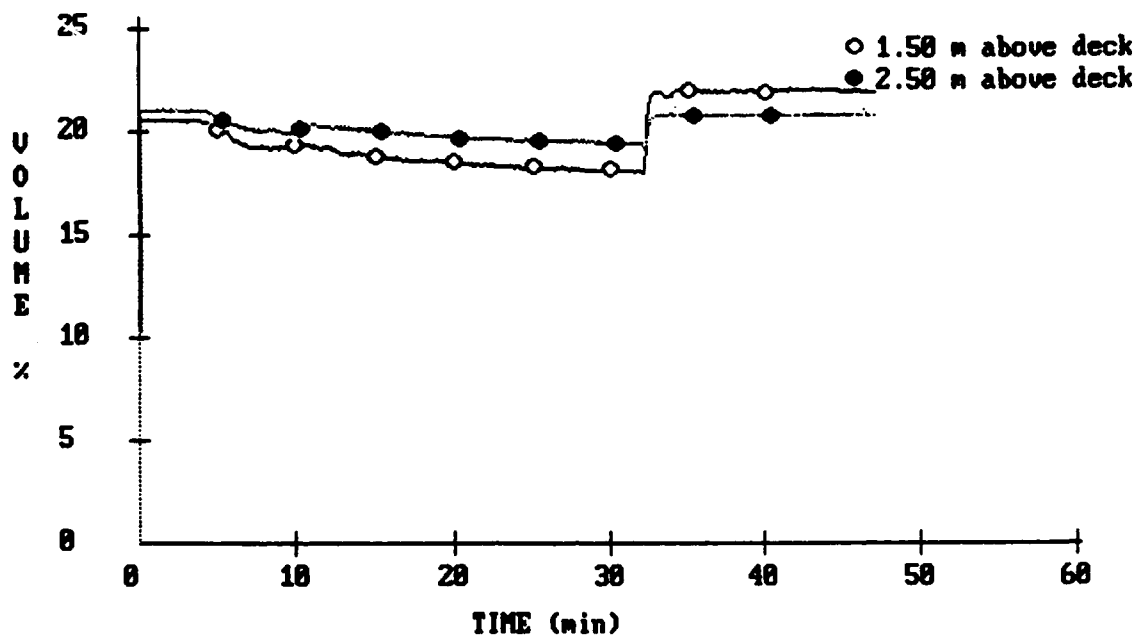


Fig. B-312-02 concentration in RICER 1 (2-76-2) during Test # 40

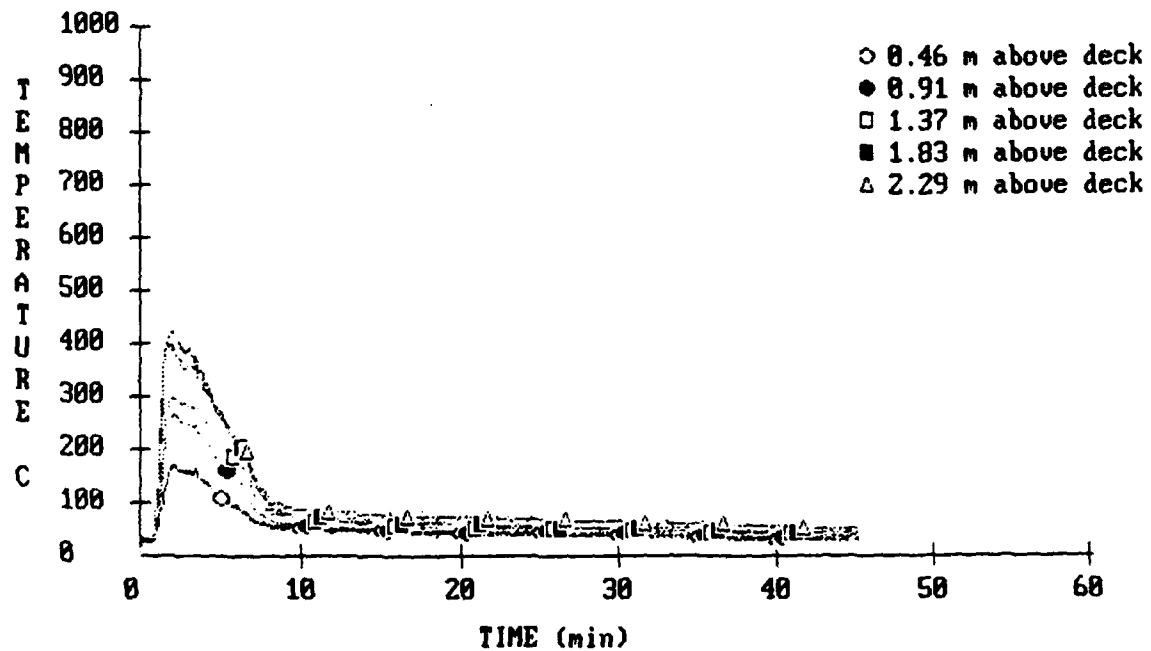


Fig. B-313- Temperature in BERTHING 2 (3-86-2) during Test # 2

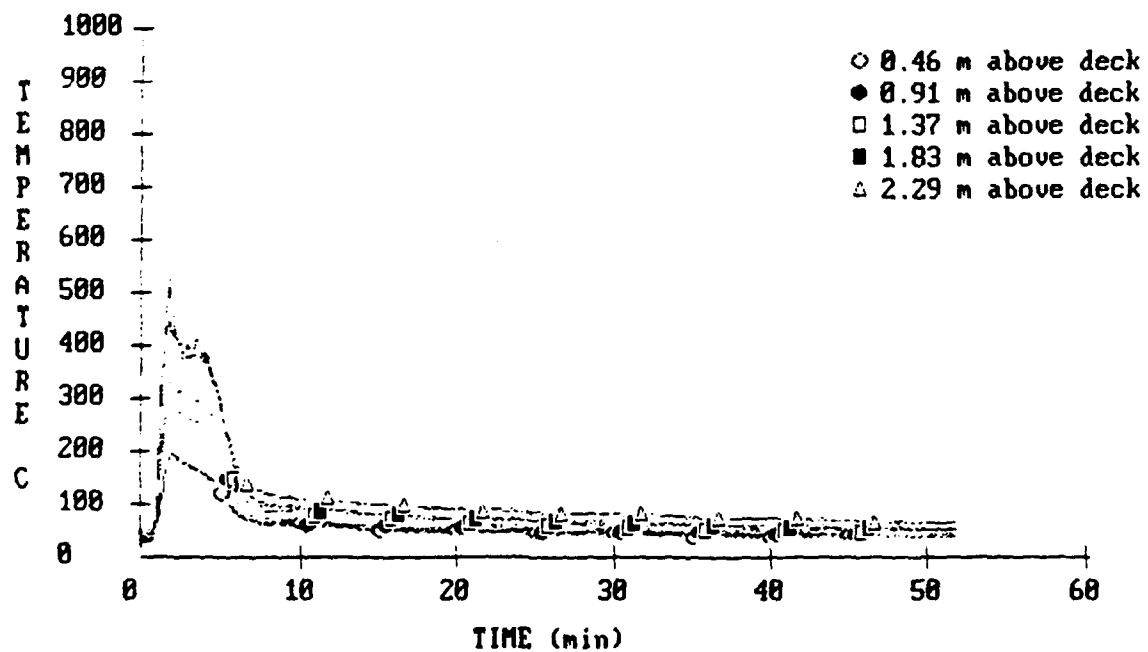


Fig. B-314- Temperature in BERTHING 2 (3-86-2) during Test # 3

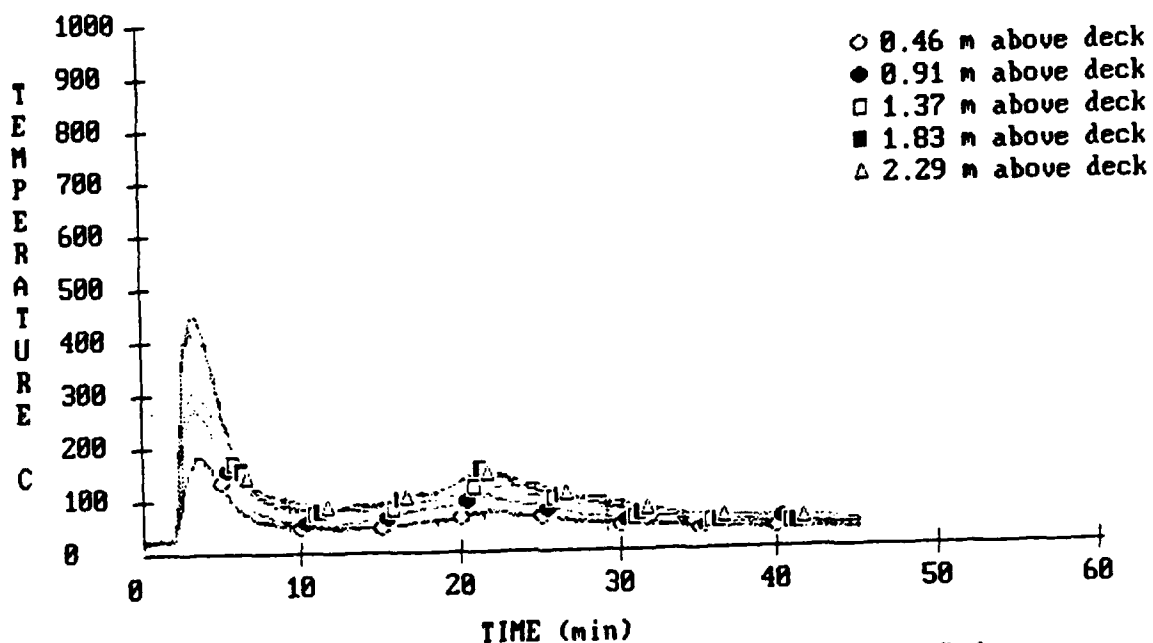


Fig. B-315- Temperature in BERTHING 2 (3-86-2) during Test # 4

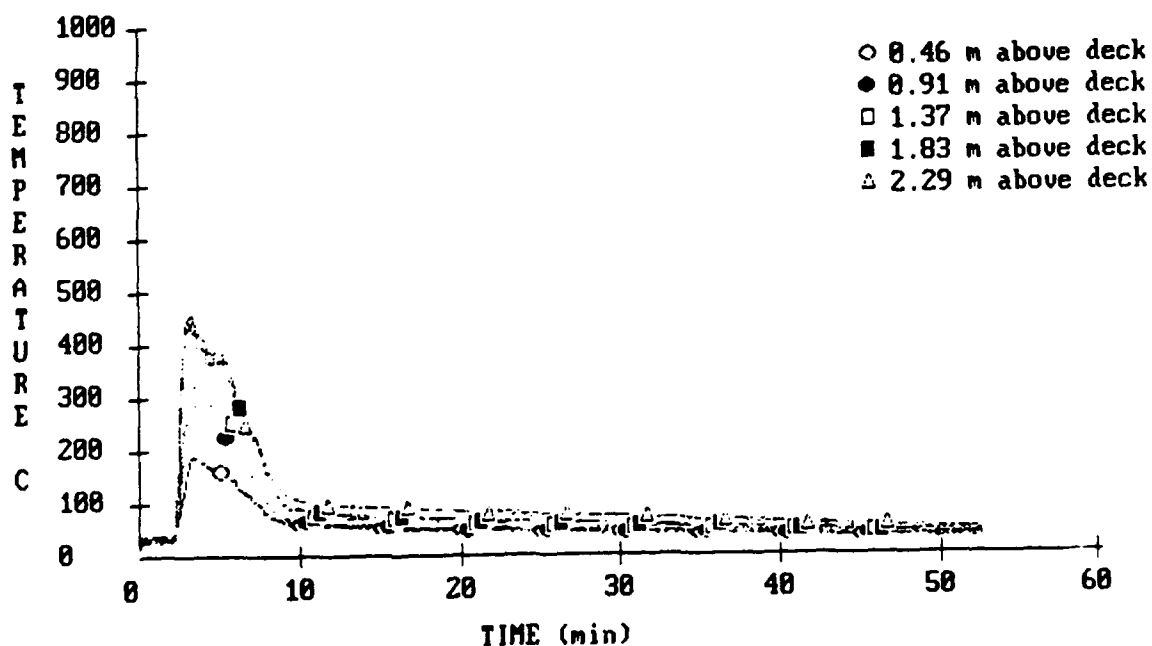


Fig. B-316- Temperature in BERTHING 2 (3-86-2) during Test # 5

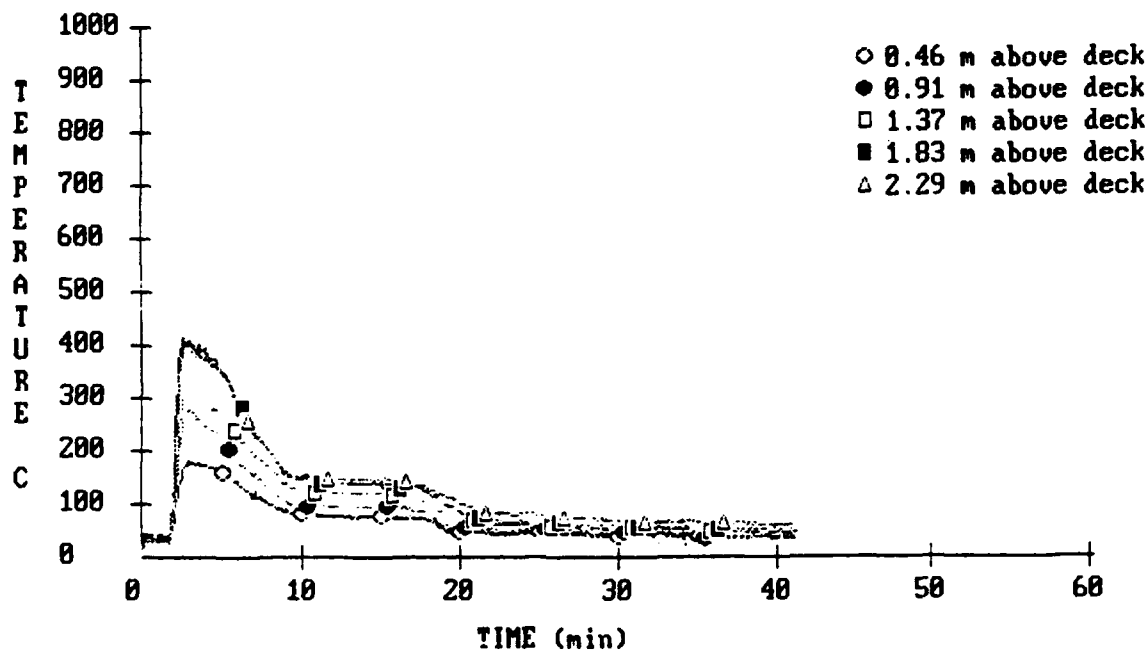


Fig. B-317- Temperature in BERTHING 2 (3-86-2) during Test # 6

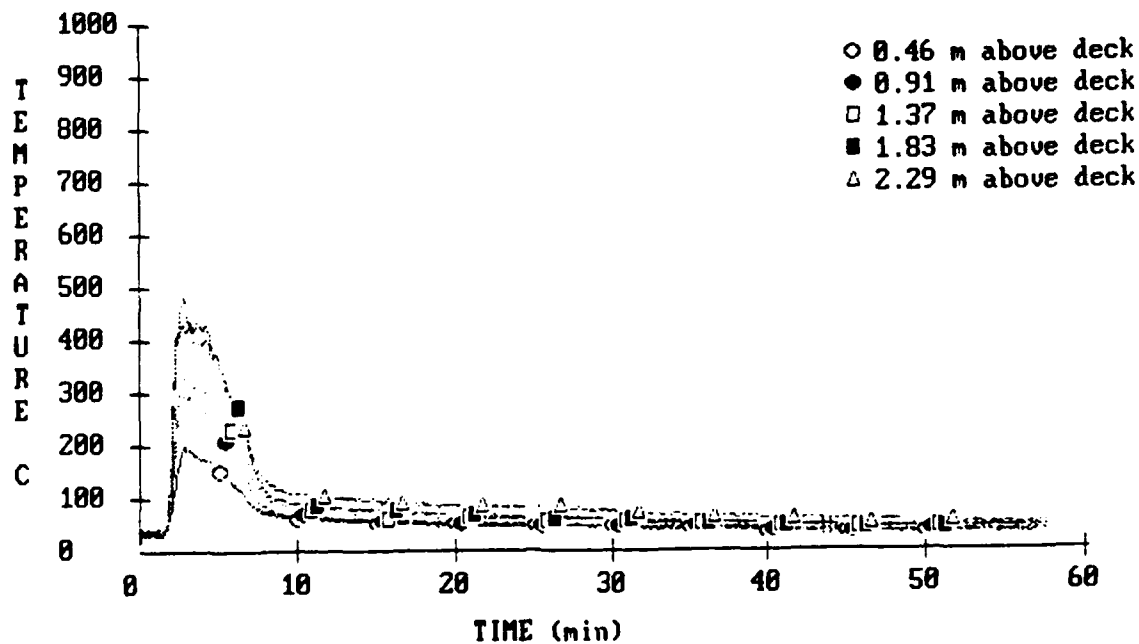


Fig. B-318- Temperature in BERTHING 2 (3-86-2) during Test # 7

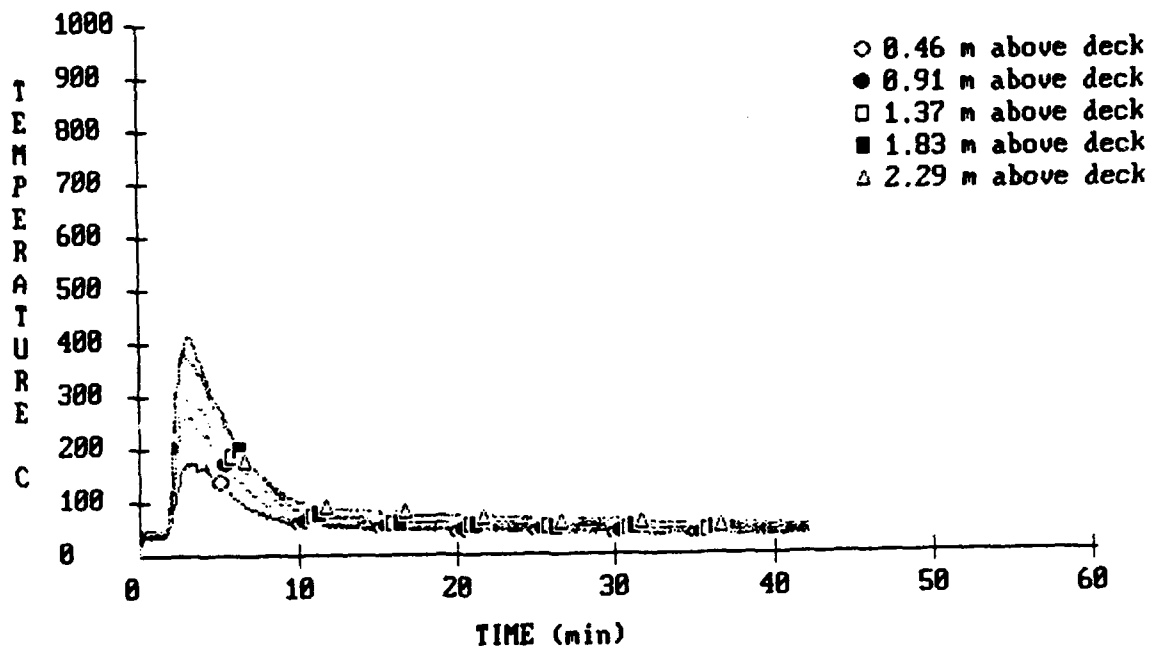


Fig. B-319- Temperature in BERTHING 2 (3-86-2) during Test # 8

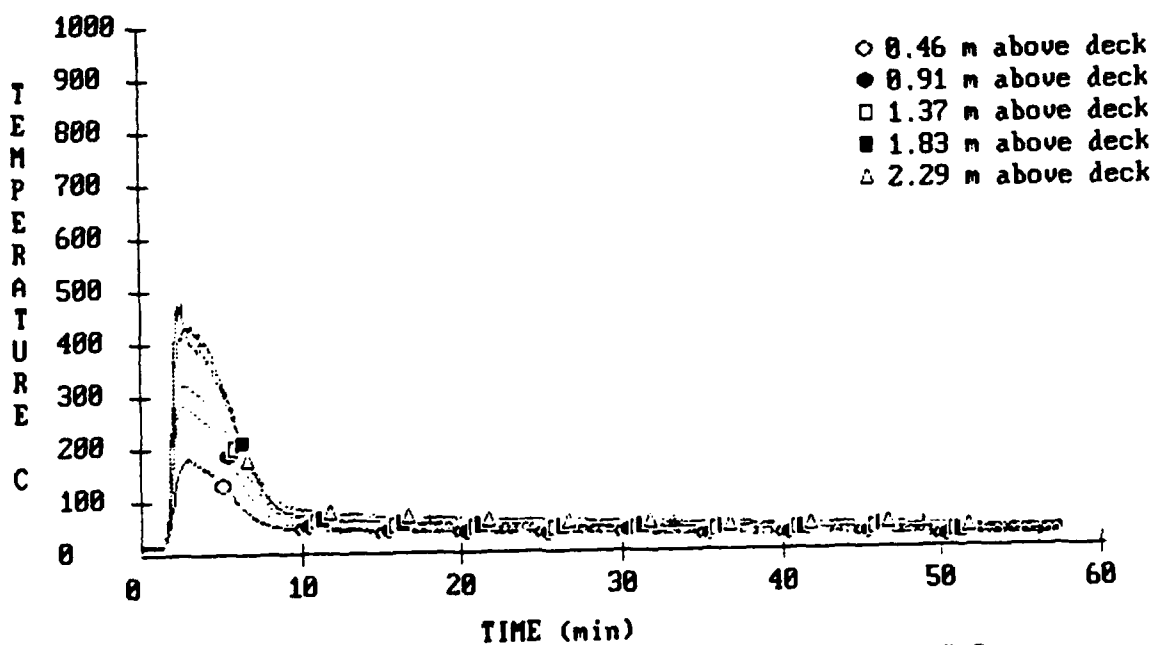


Fig. B-320- Temperature in BERTHING 2 (3-86-2) during Test # 9

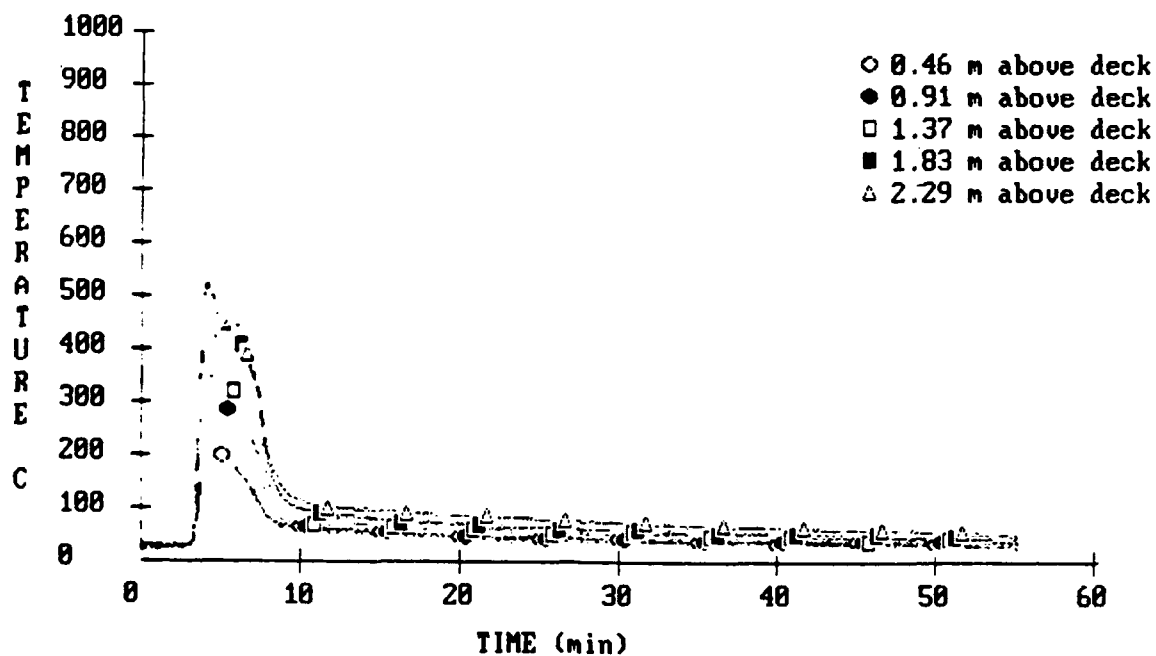


Fig. B-321- Temperature in BERTHING 2 (3-86-2) during Test # 10

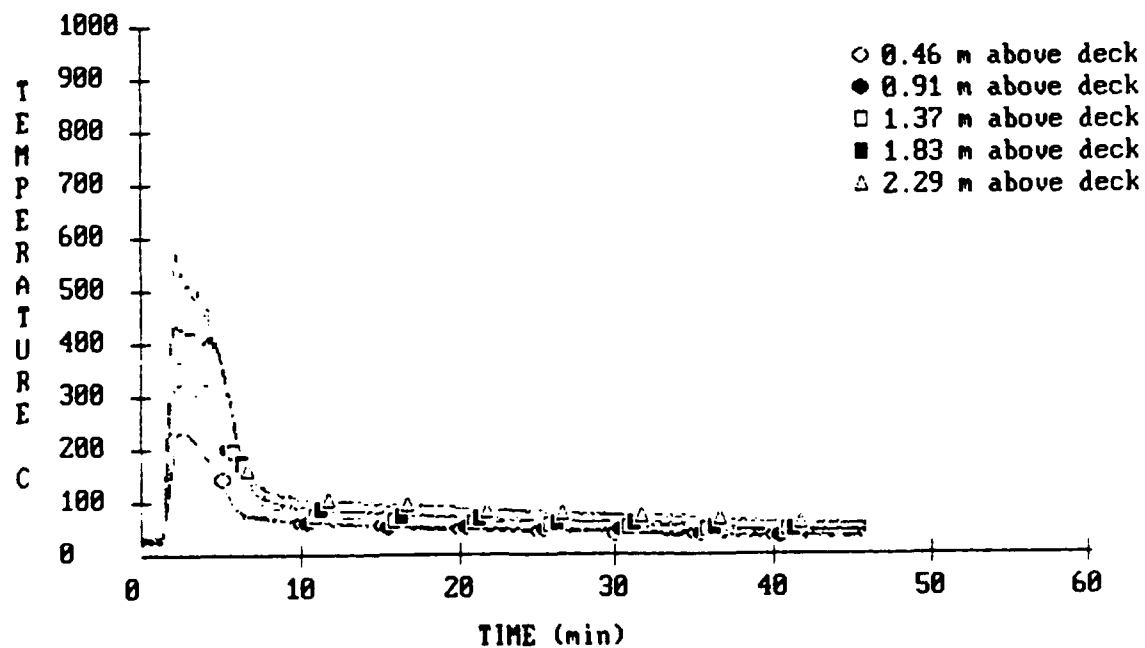


Fig. B-322- Temperature in BERTHING 2 (3-86-2) during Test # 11

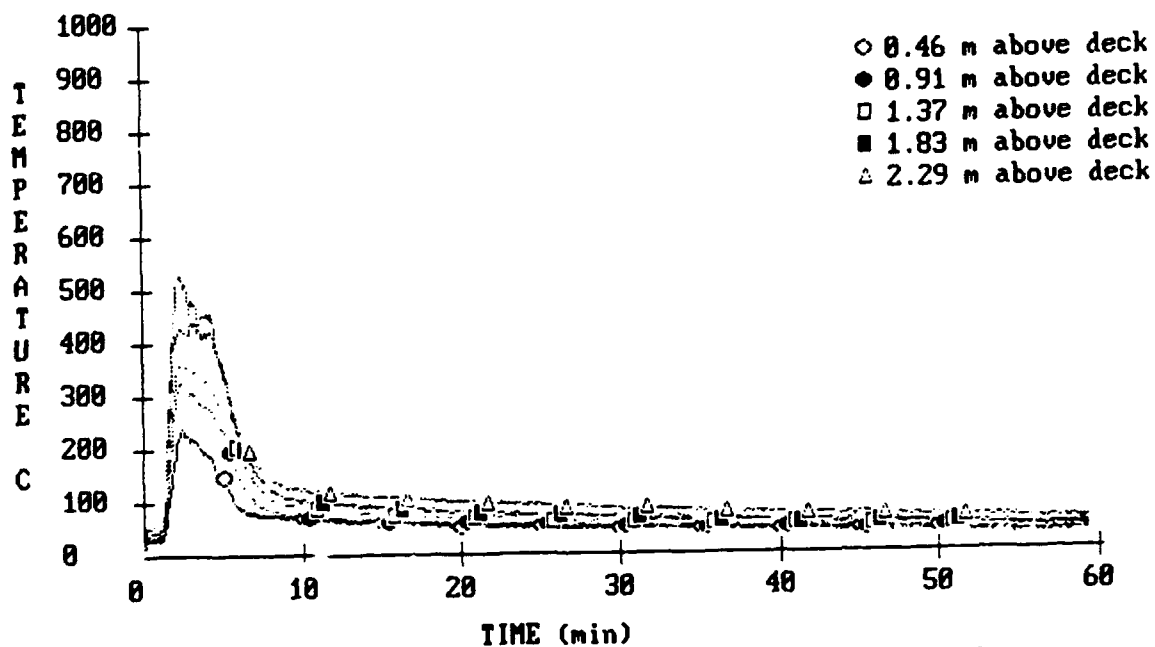


Fig. B-323- Temperature in BERTHING 2 (3-86-2) during Test # 12

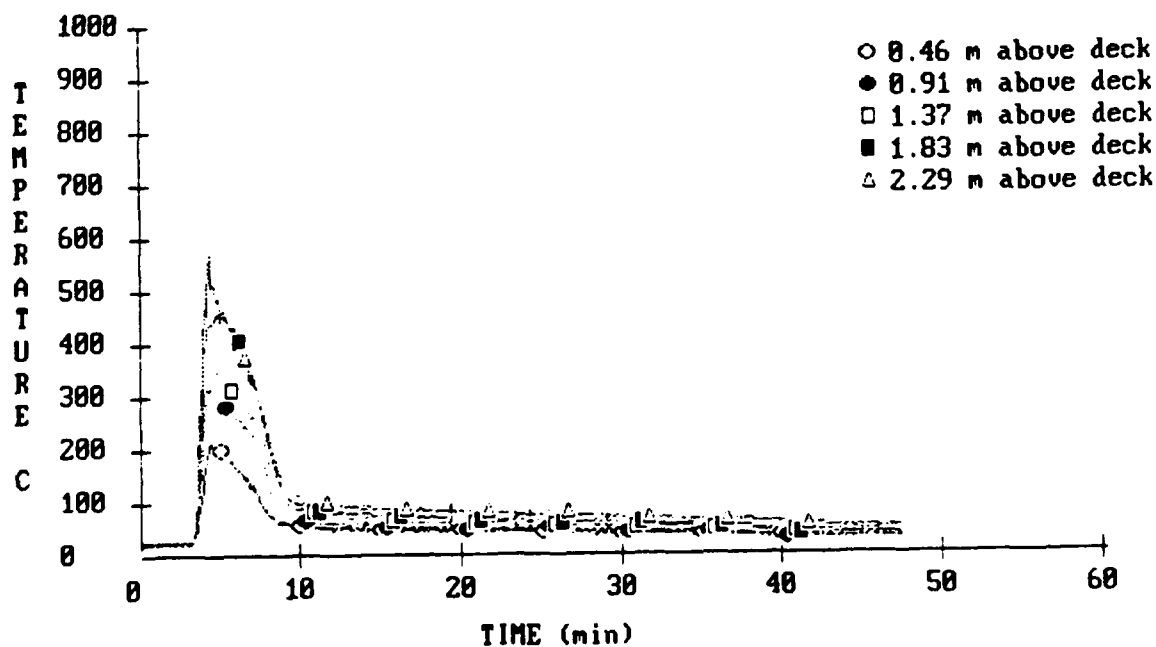


Fig. B-324- Temperature in BERTHING 2 (3-86-2) during Test # 13

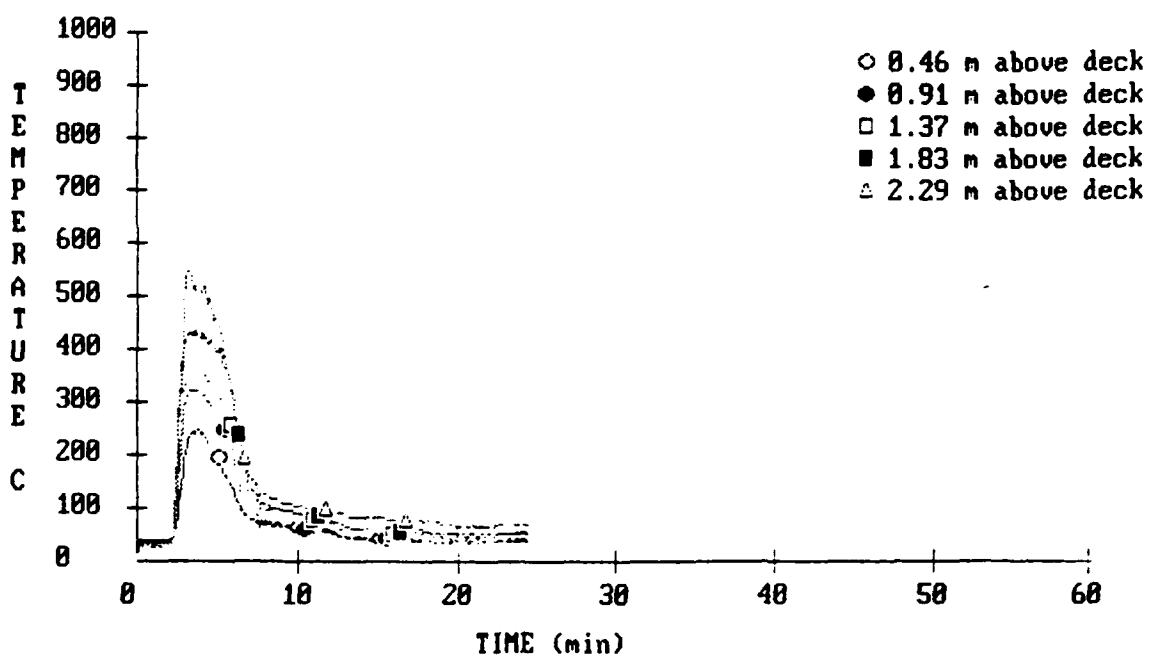


Fig. B-325- Temperature in BERTHING 2 (3-86-2) during Test # 14

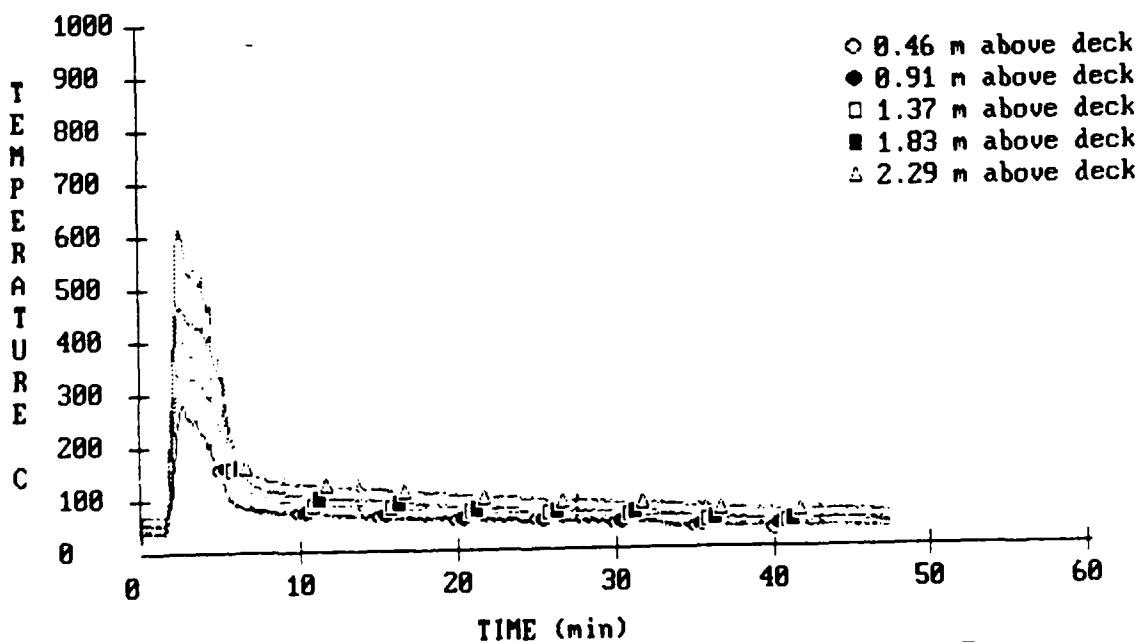


Fig. B-326- Temperature in BERTHING 2 (3-86-2) during Test # 15



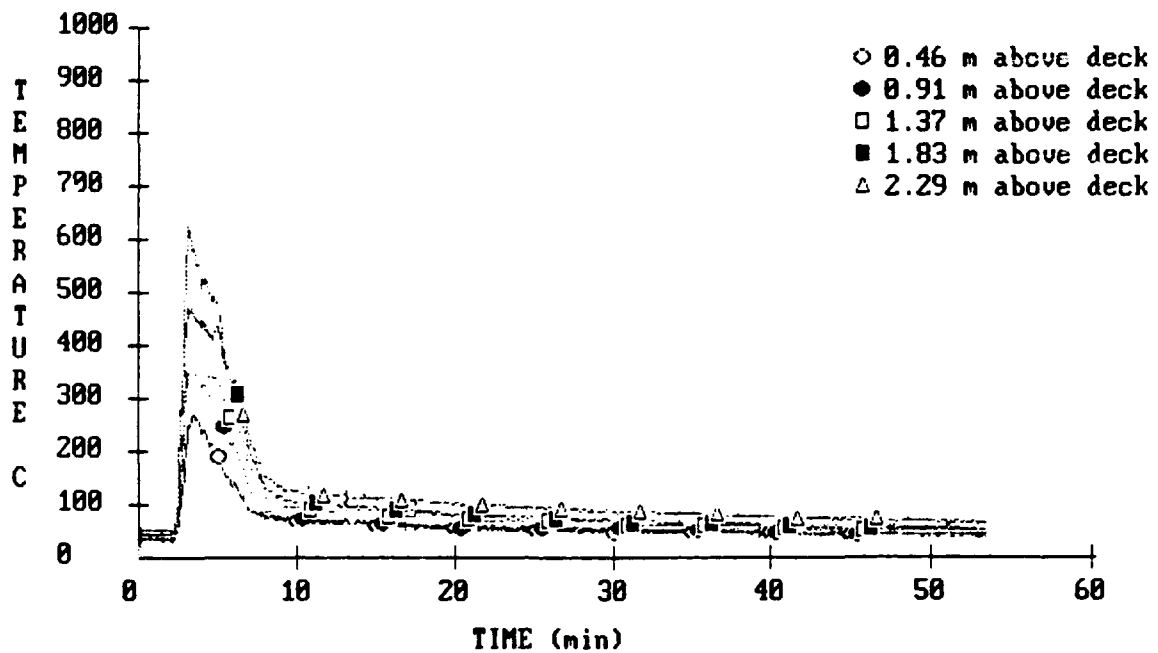


Fig. B-327- Temperature in BERTHING 2 (3-86-2) during Test # 16

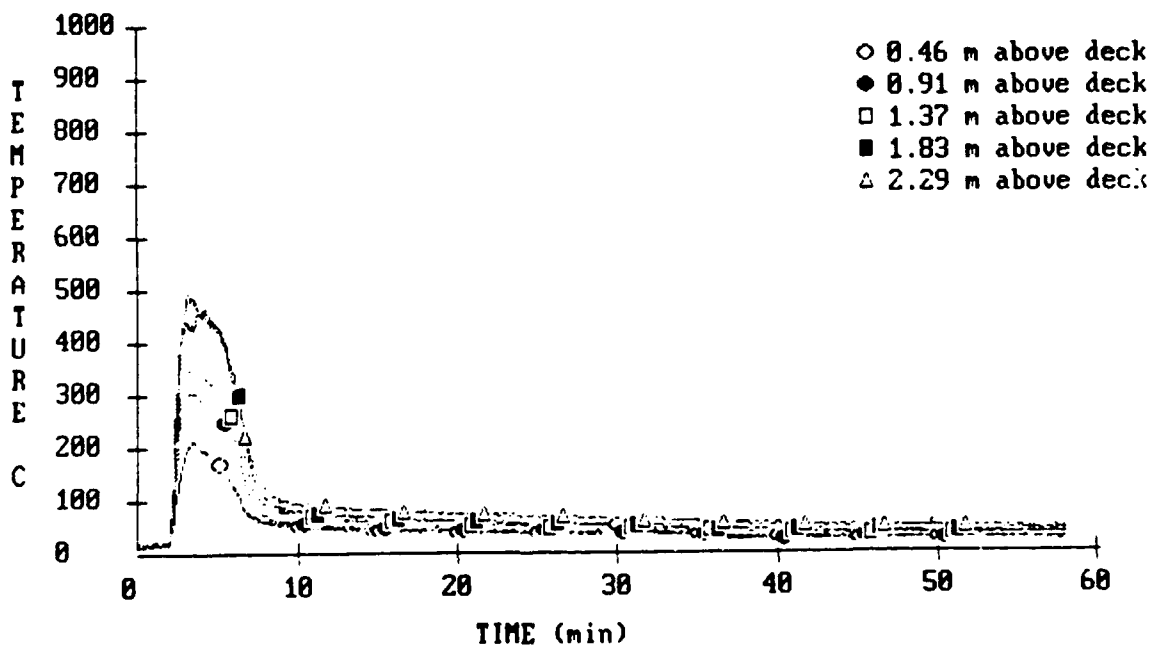


Fig. B-328- Temperature in BERTHING 2 (3-86-2) during Test # 17

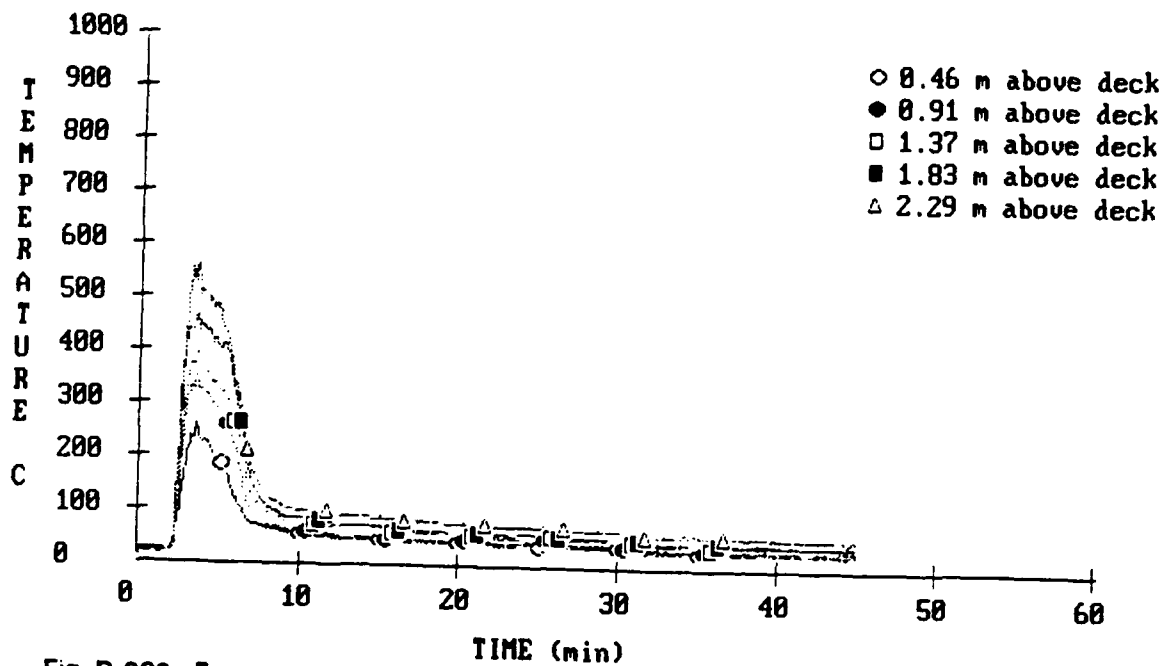


Fig. B-329- Temperature in BERTHING 2 (3-86-2) during Test # 18

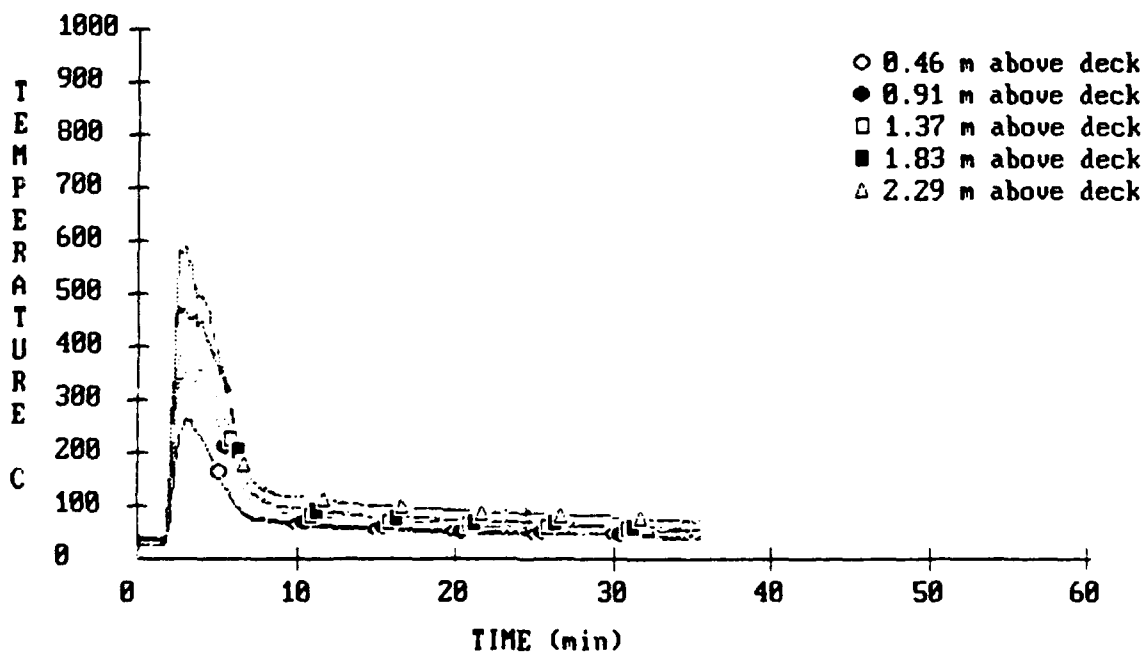


Fig. B-330- Temperature in BERTHING 2 (3-86-2) during Test # 19

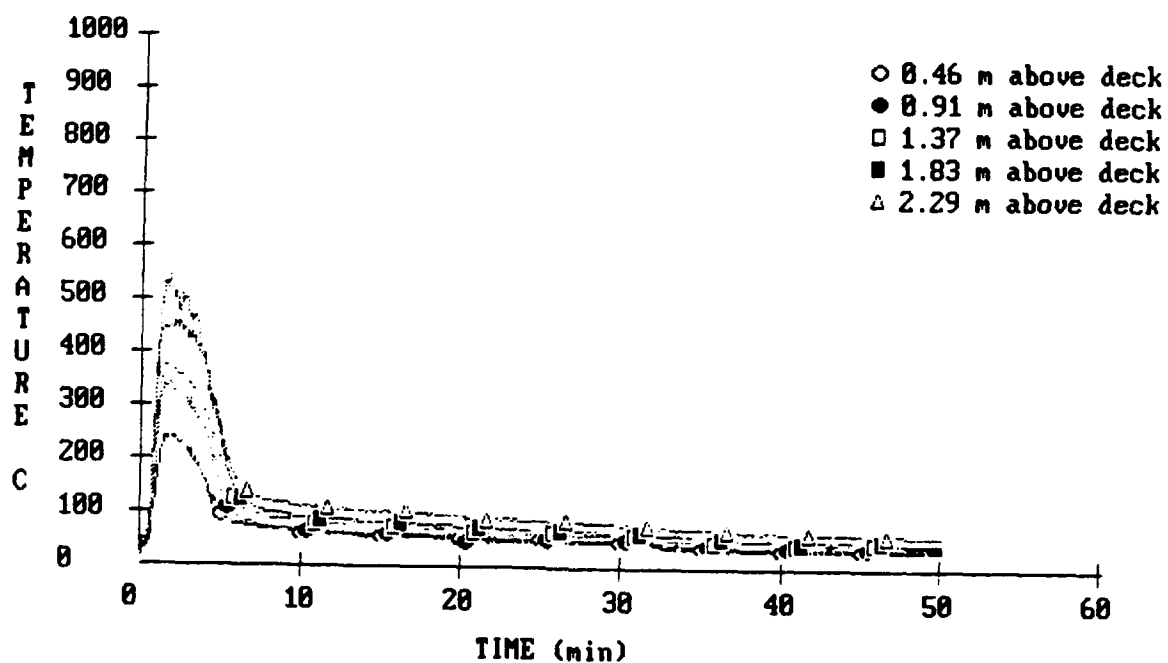


Fig. B-331- Temperature in BERTHING 2 (3-86-2) during Test # 20

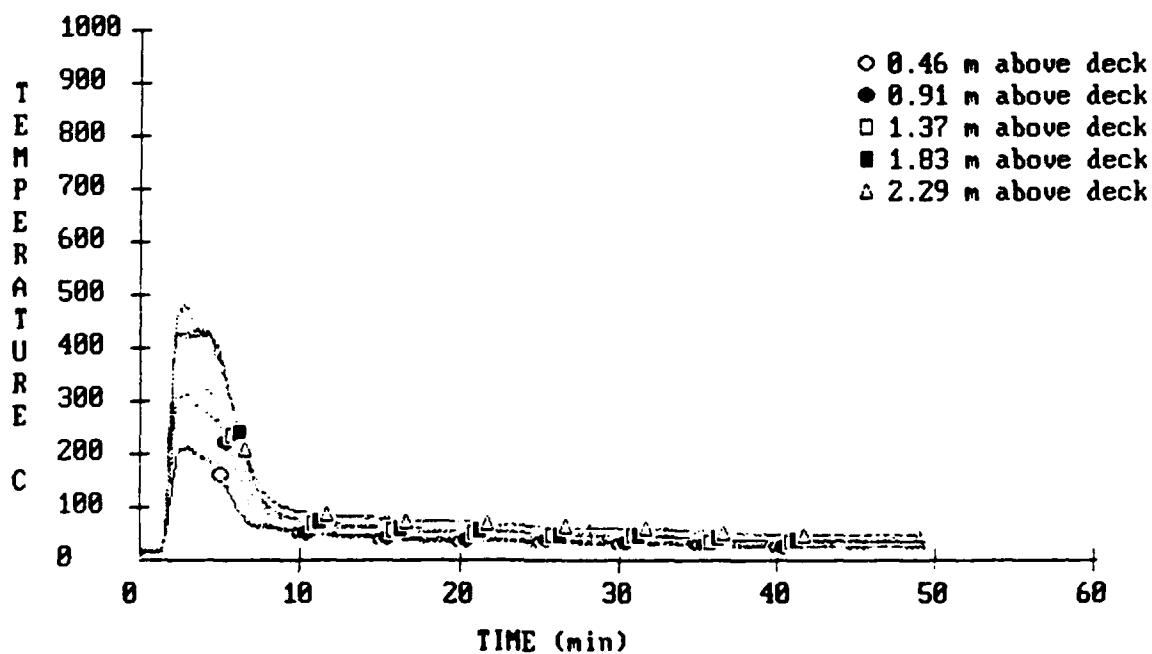


Fig. B-332- Temperature in BERTHING 2 (3-86-2) during Test # 21

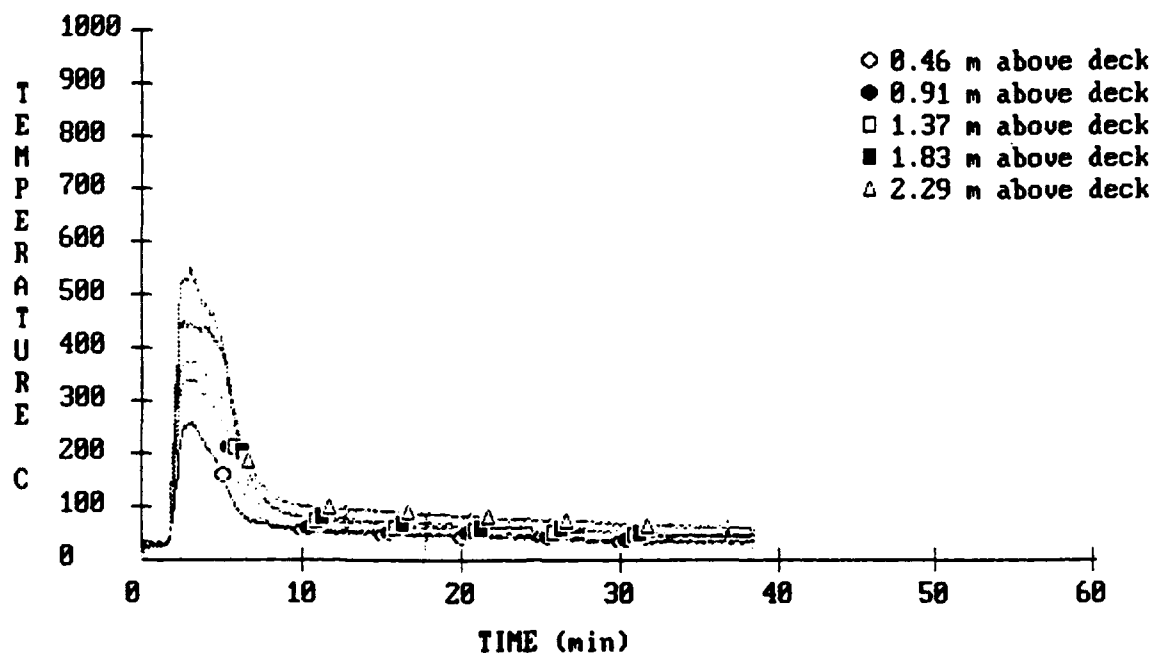


Fig. B-333- Temperature in BERTHING 2 (3-86-2) during Test # 22

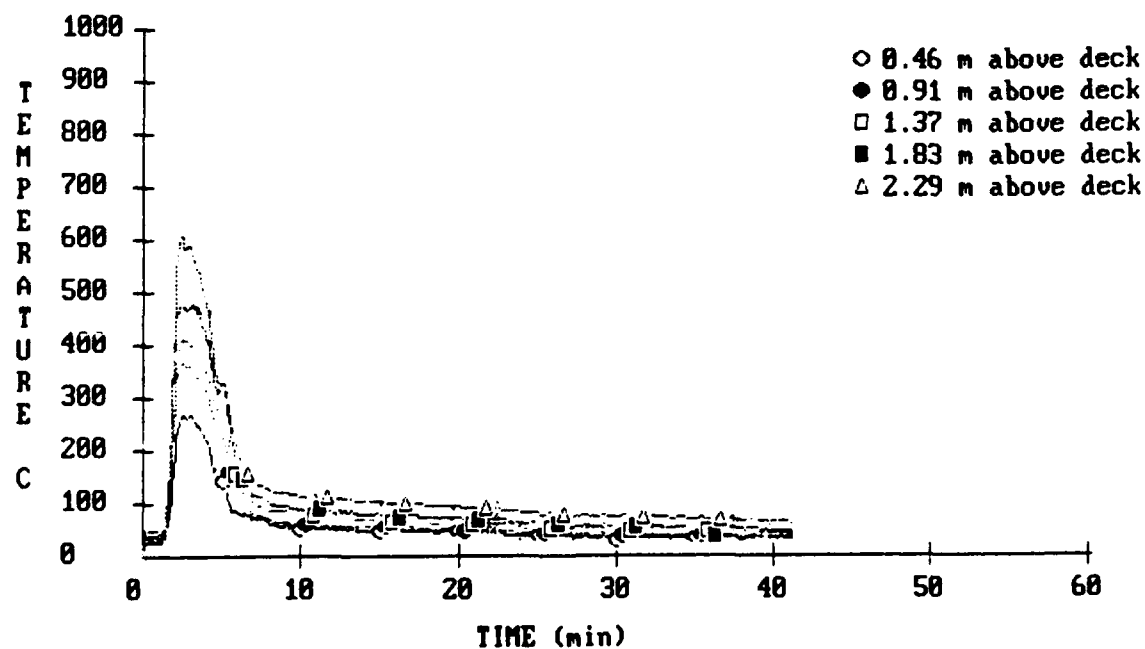


Fig. B-334- Temperature in BERTHING 2 (3-86-2) during Test # 23

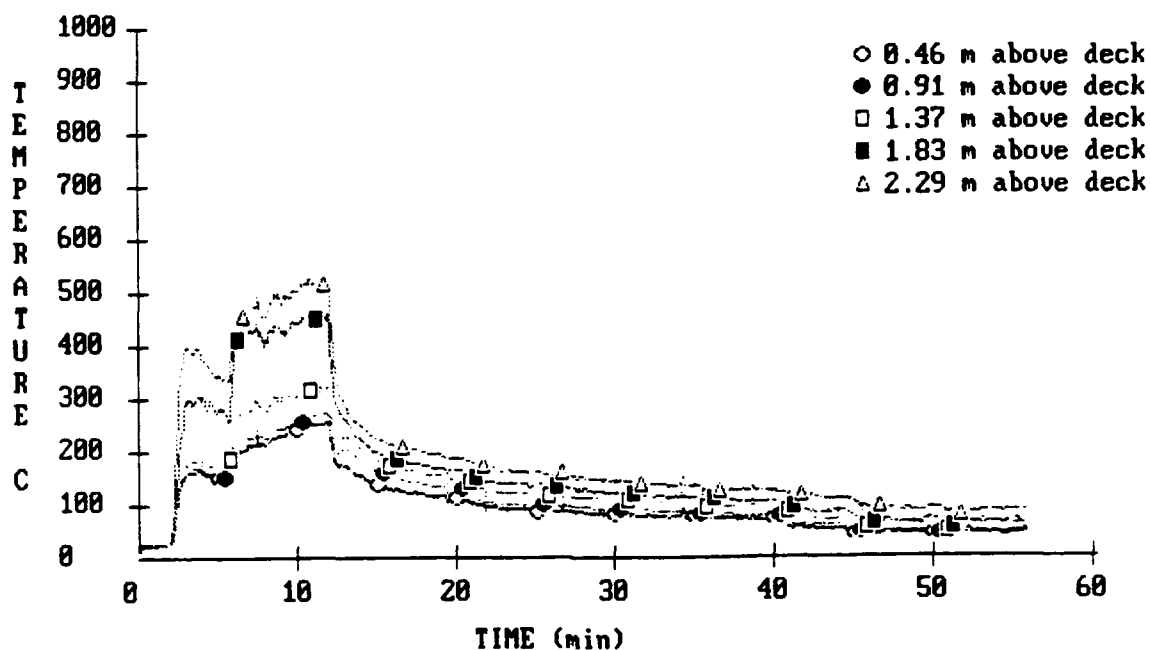


Fig. B-335- Temperature in BERTHING 2 (3-86-2) during Test # 24

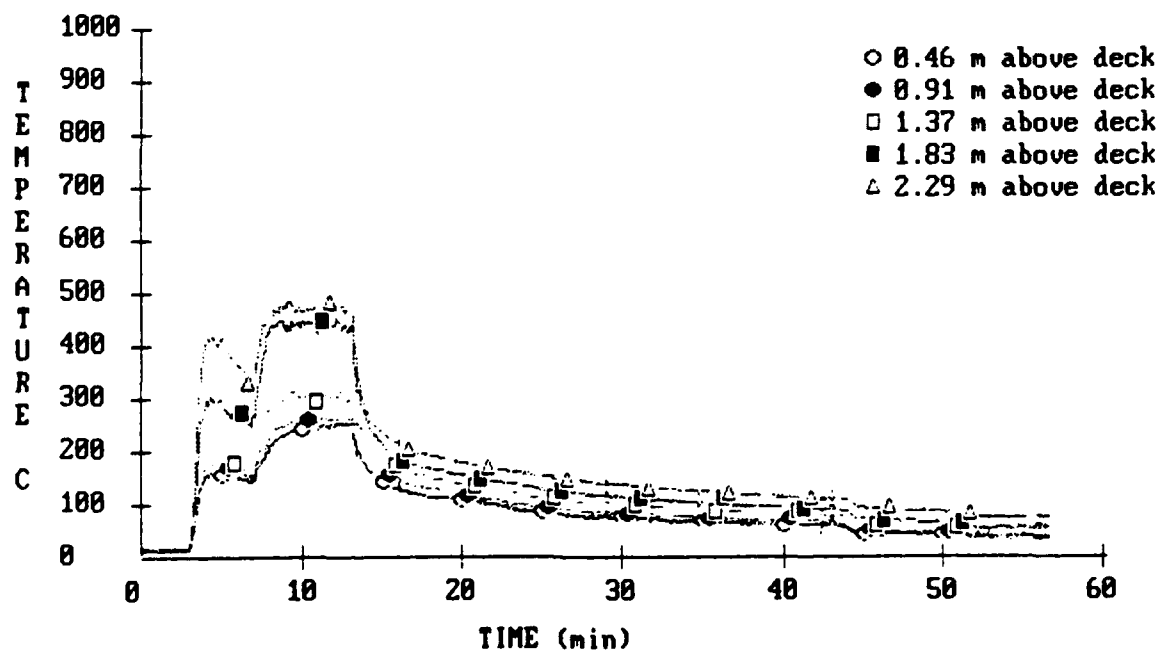


Fig. B-336- Temperature in BERTHING 2 (3-86-2) during Test # 25

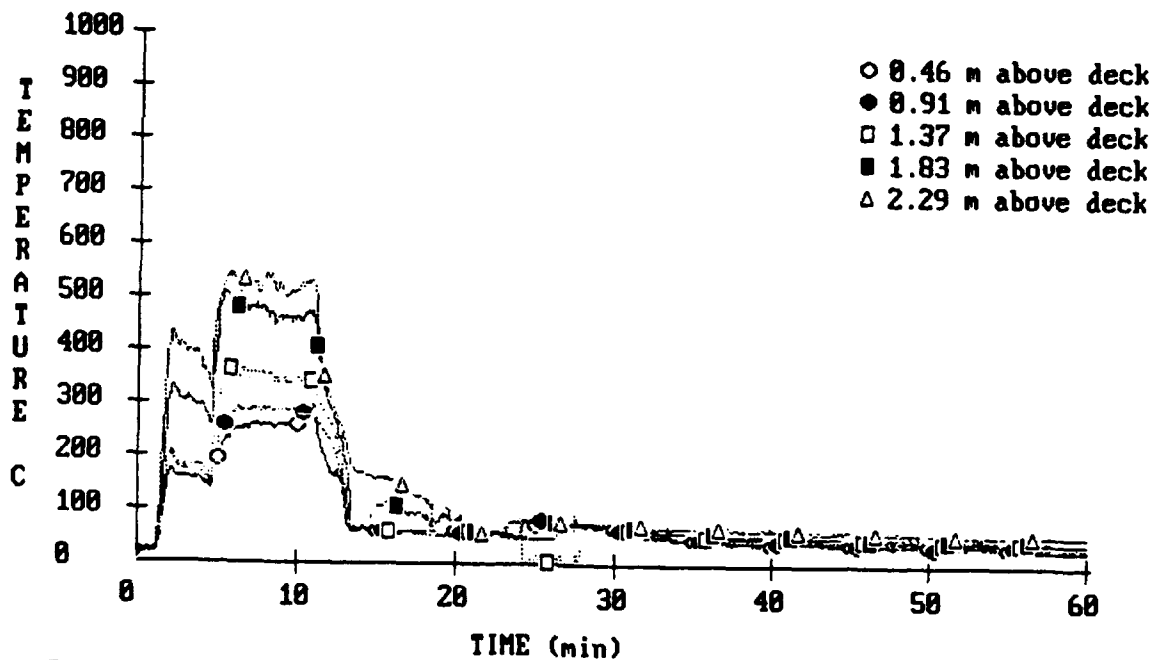


Fig. B-337- Temperature in BERTHING 2 (3-86-2) during Test # 26

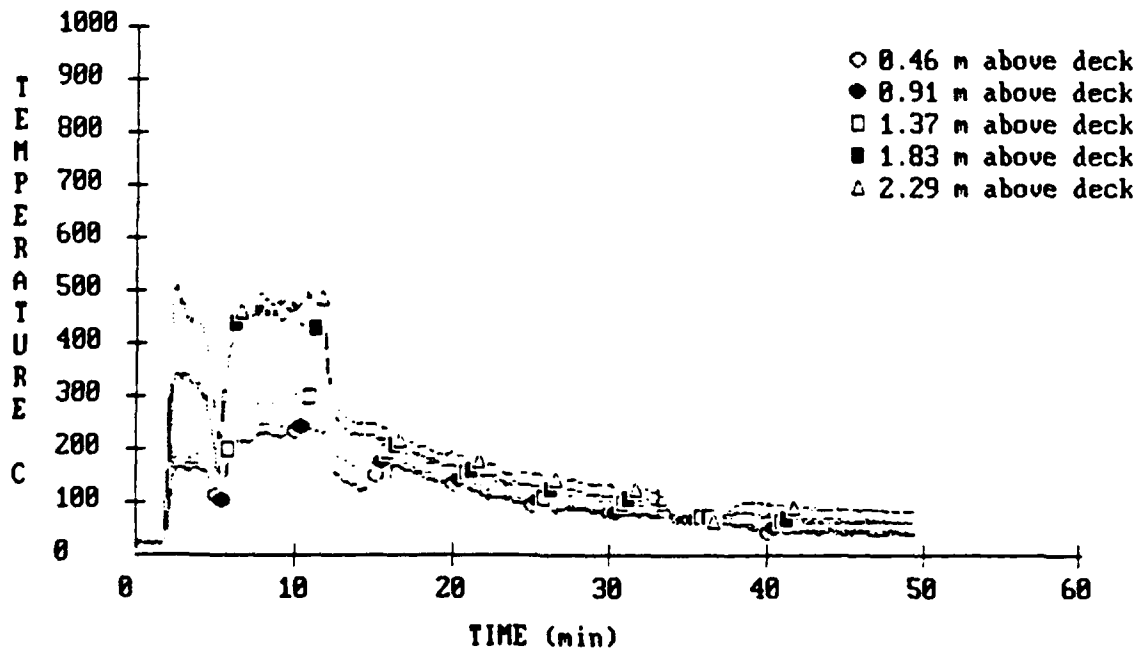


Fig. B-338- Temperature in BERTHING 2 (3-86-2) during Test # 27

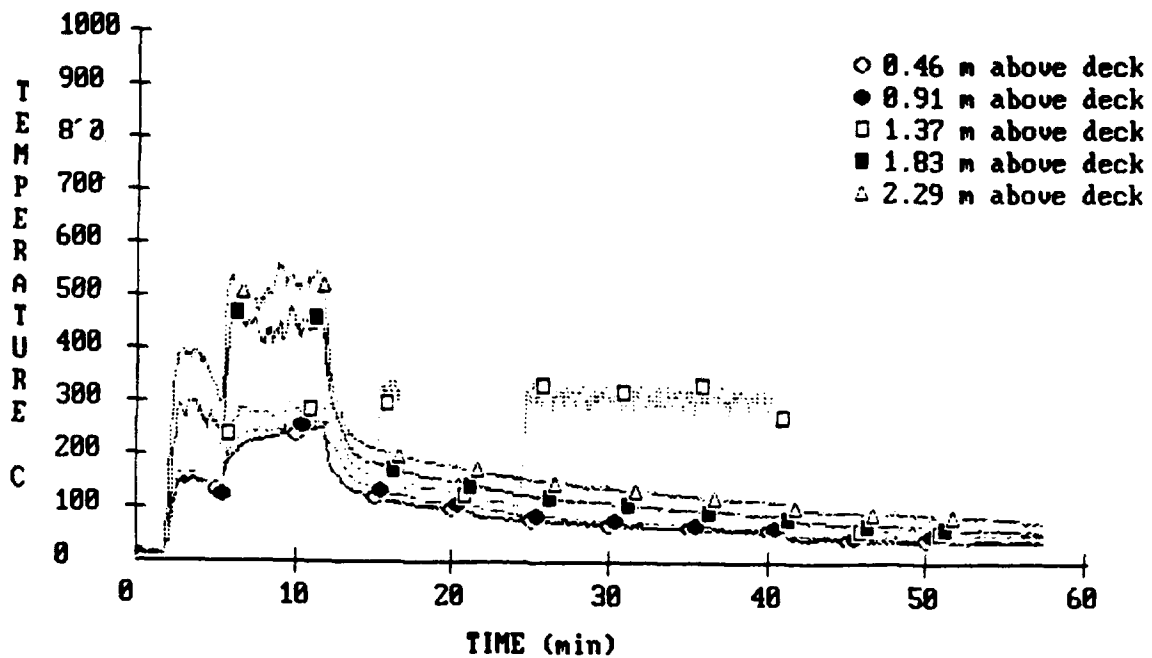


Fig. B-339- Temperature in BERTHING 2 (3-86-2) during Test # 28

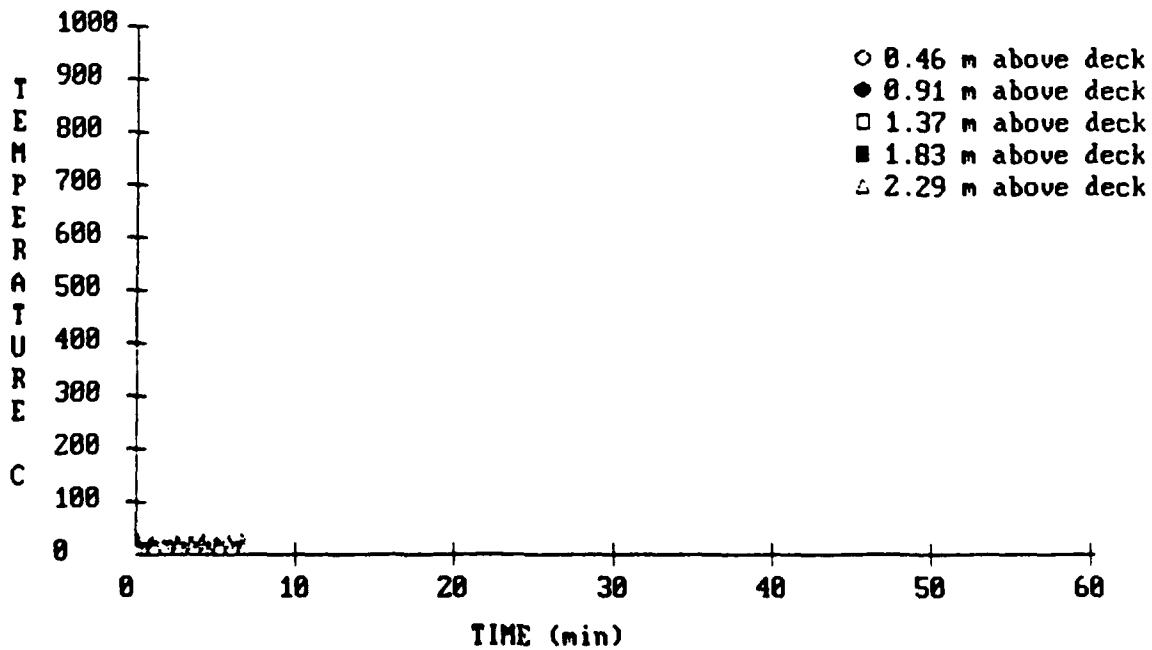


Fig. B-340- Temperature in BERTHING 2 (3-86-2) during Test # 29

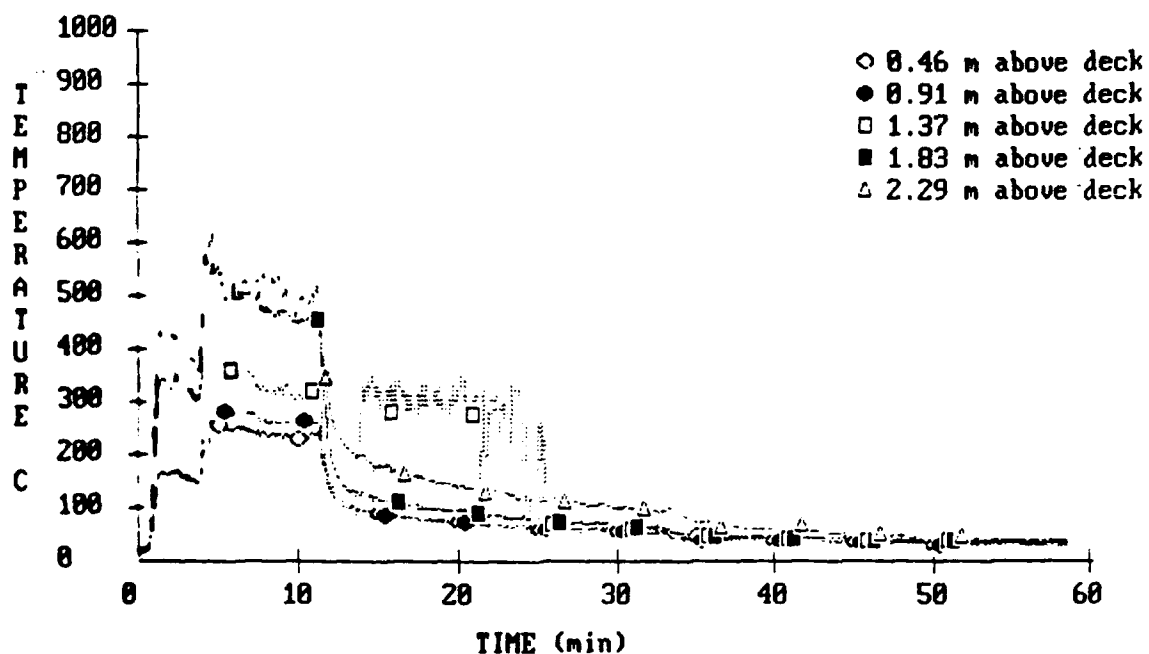


Fig. B-341- Temperature in BERTHING 2 (3-86-2) during Test # 30

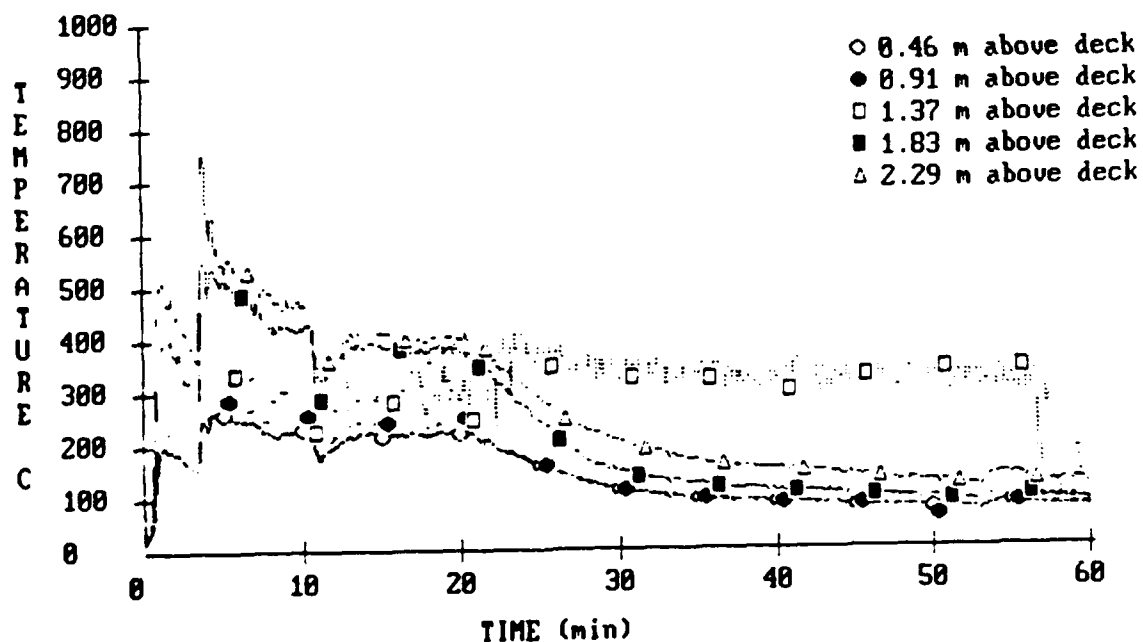


Fig. B-342- Temperature in BERTHING 2 (3-86-2) during Test # 31



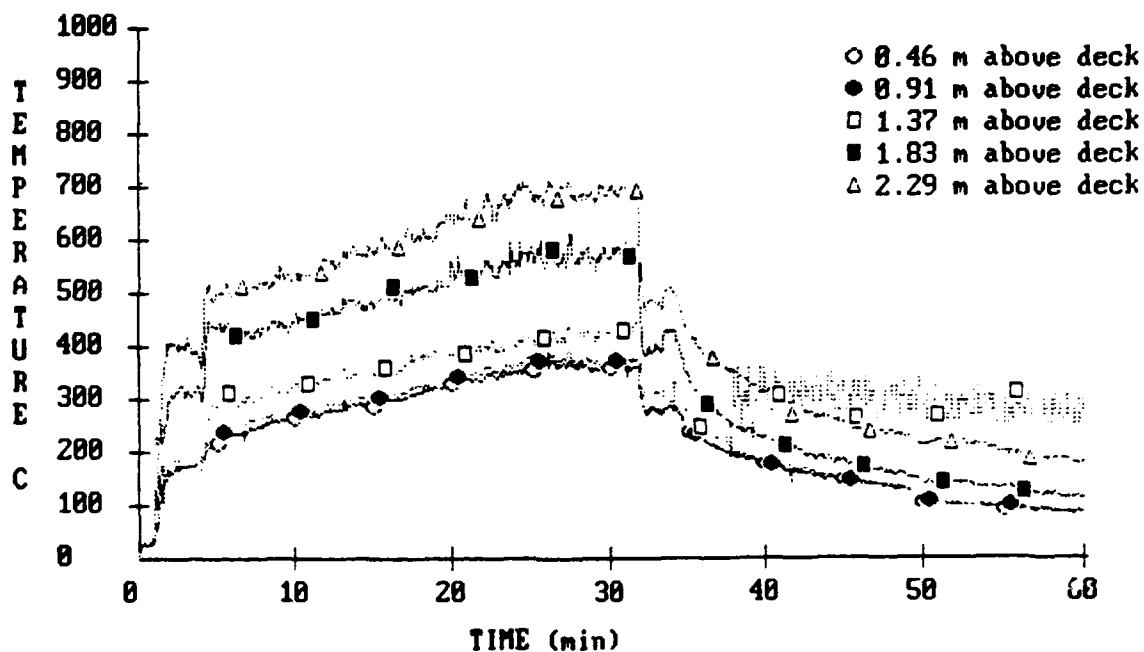


Fig. B-343- Temperature in BERTHING 2 (3-86-2) during Test # 32

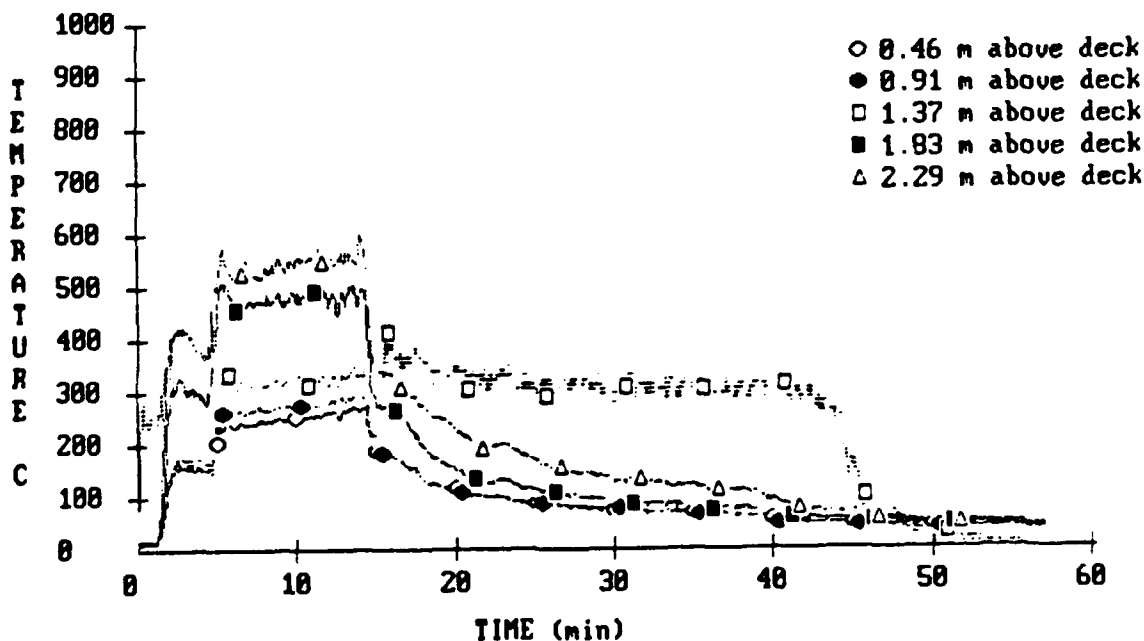


Fig. B-344- Temperature in BERTHING 2 (3-86-2) during Test # 33

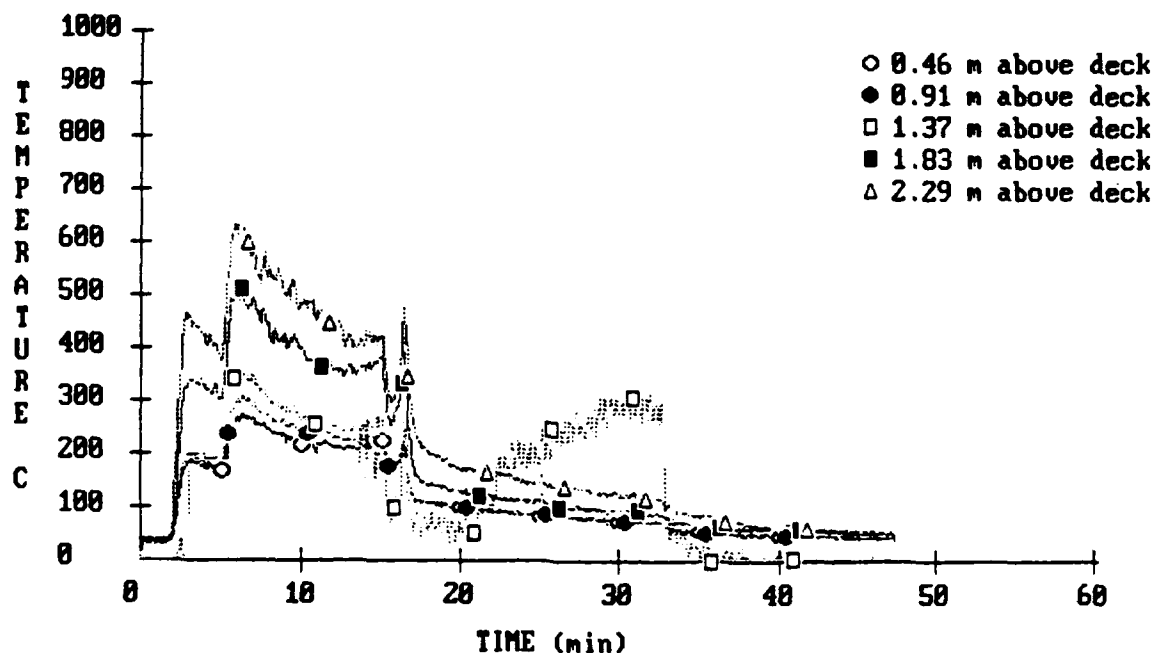


Fig. B-345- Temperature in BERTHING 2 (3-86-2) during Test # 34

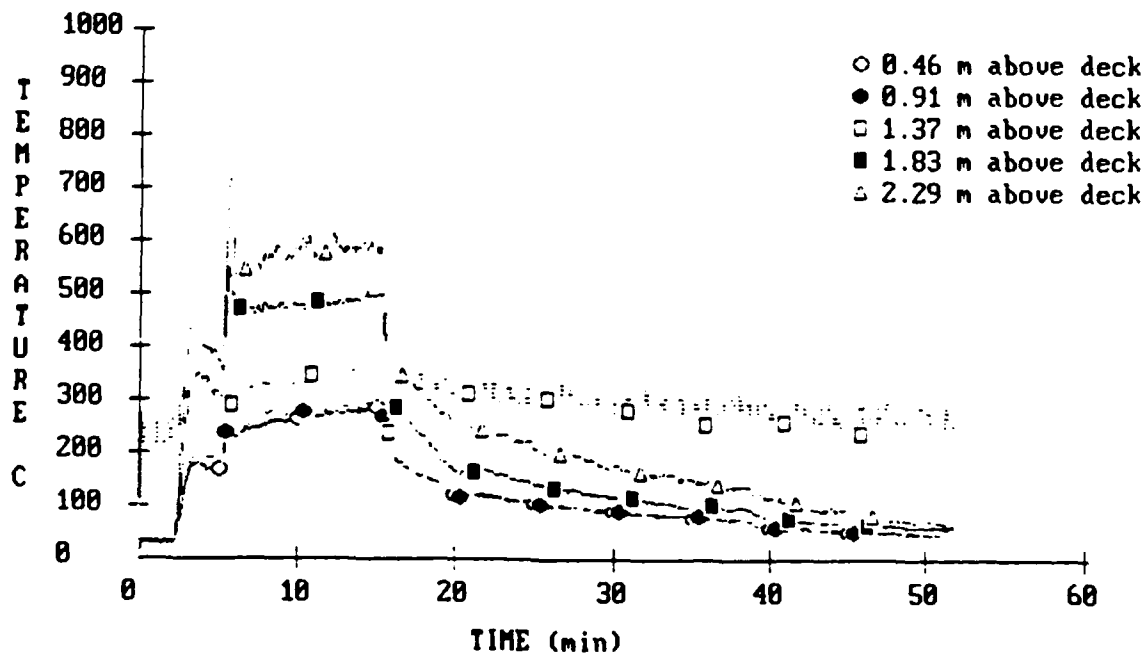


Fig. B-346- Temperature in BERTHING 2 (3-86-2) during Test # 35

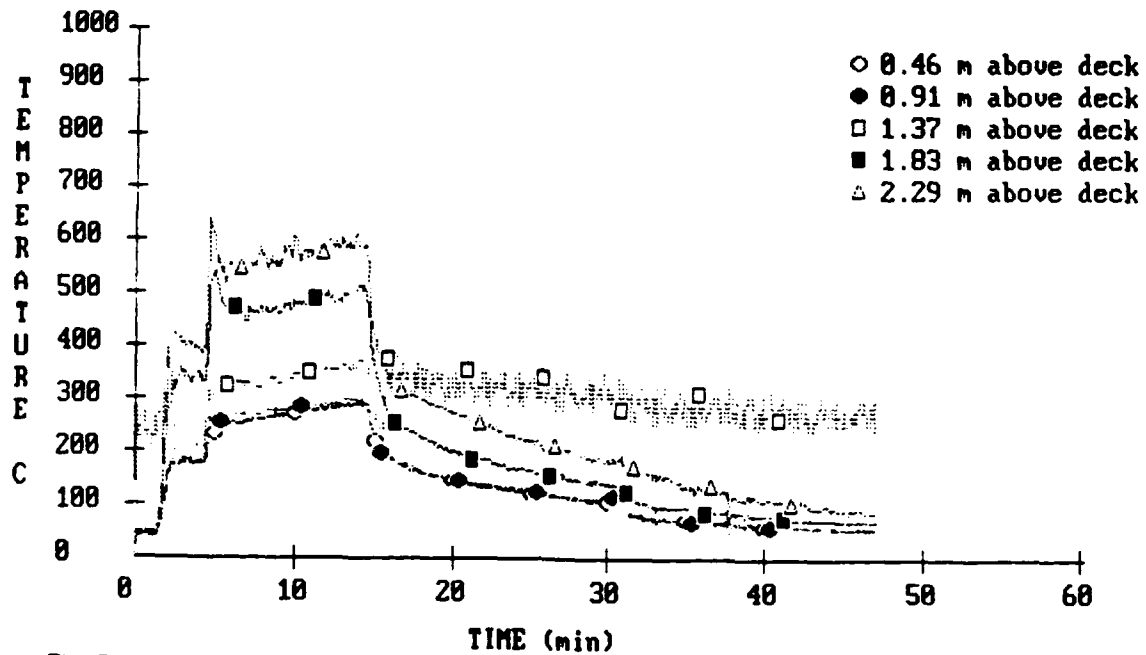


Fig. B-347- Temperature in BERTHING 2 (3-86-2) during Test # 36

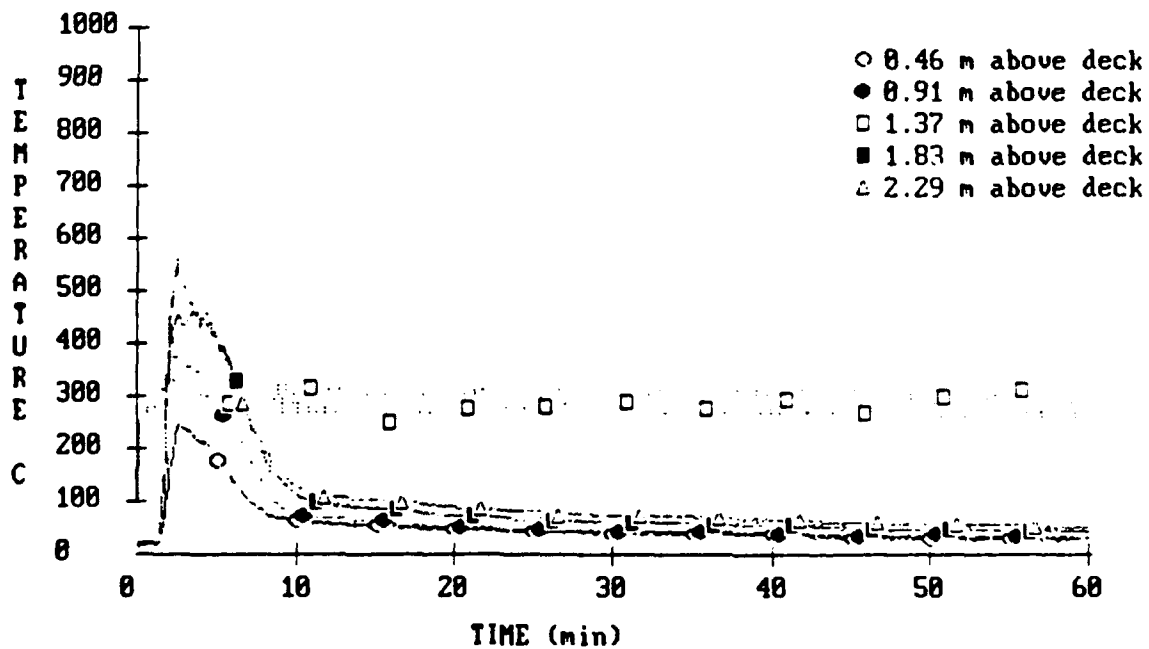


Fig. B-348- Temperature in BERTHING 2 (3-86-2) during Test # 37

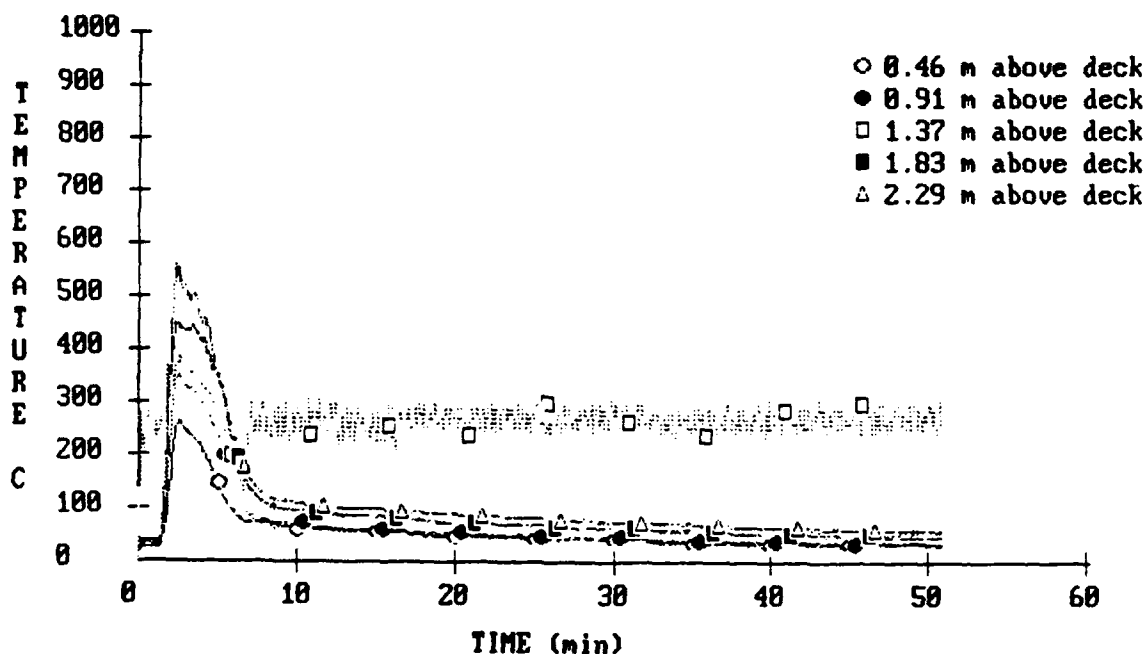


Fig. B-349- Temperature in BERTHING 2 (3-86-2) during Test # 38

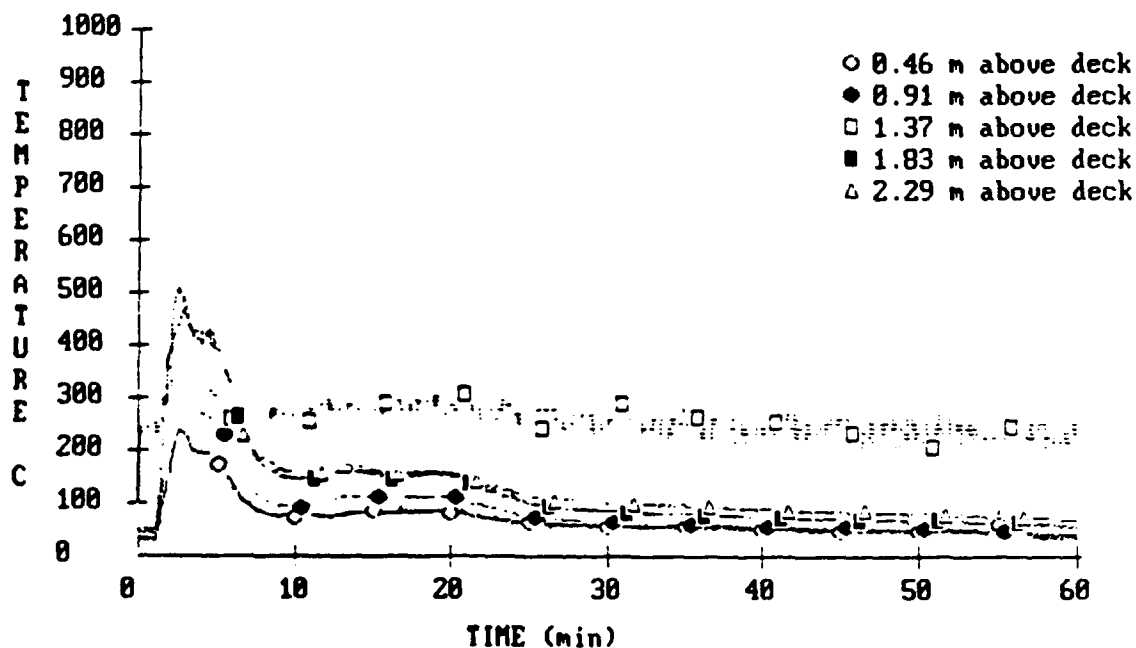


Fig. B-350- Temperature in BERTHING 2 (3-86-2) during Test # 39

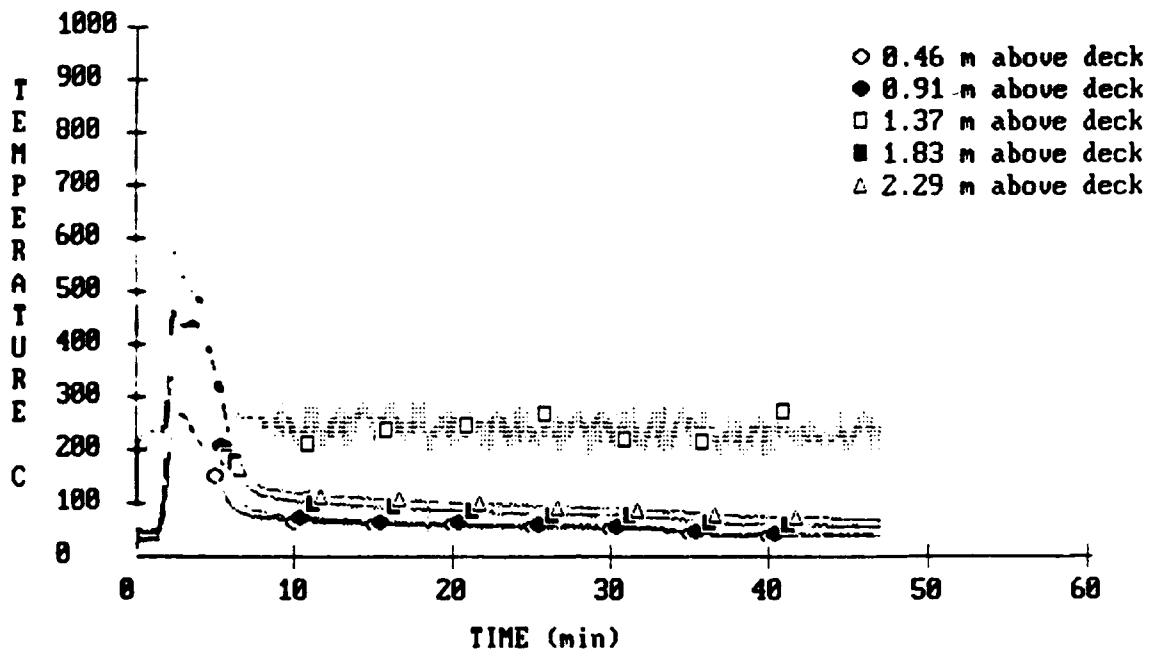


Fig. B-351- Temperature in BERTHING 2 (3-86-2) during Test # 48

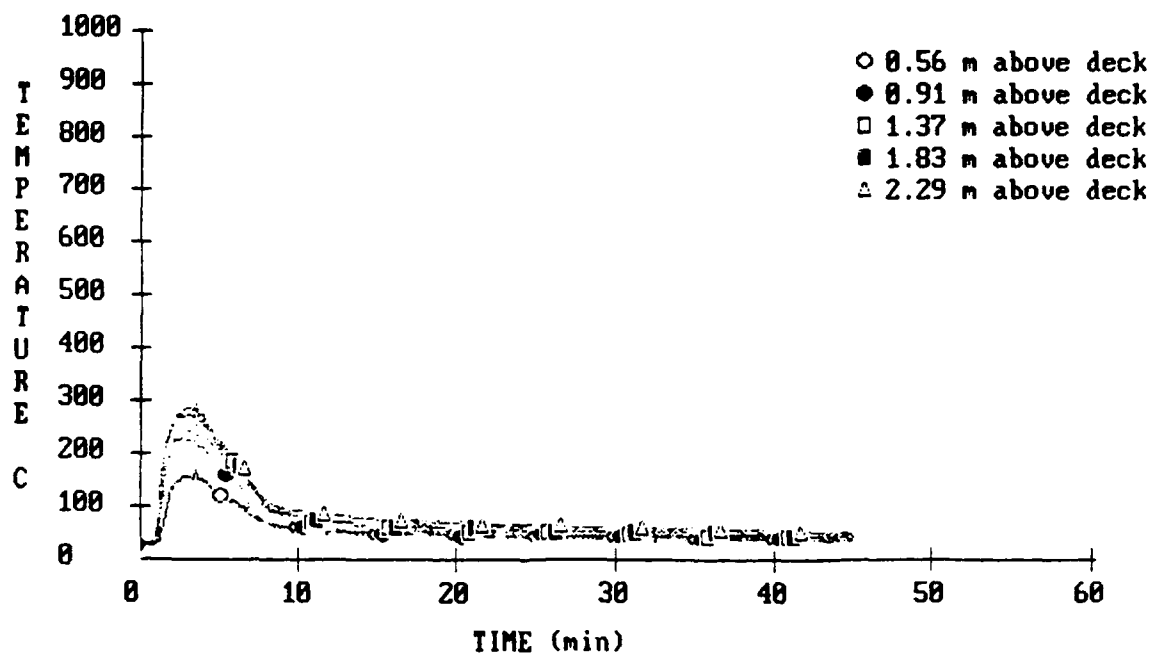


Fig. B-352- Temperature in BERTHING 2 (3-83-6) during Test # 2

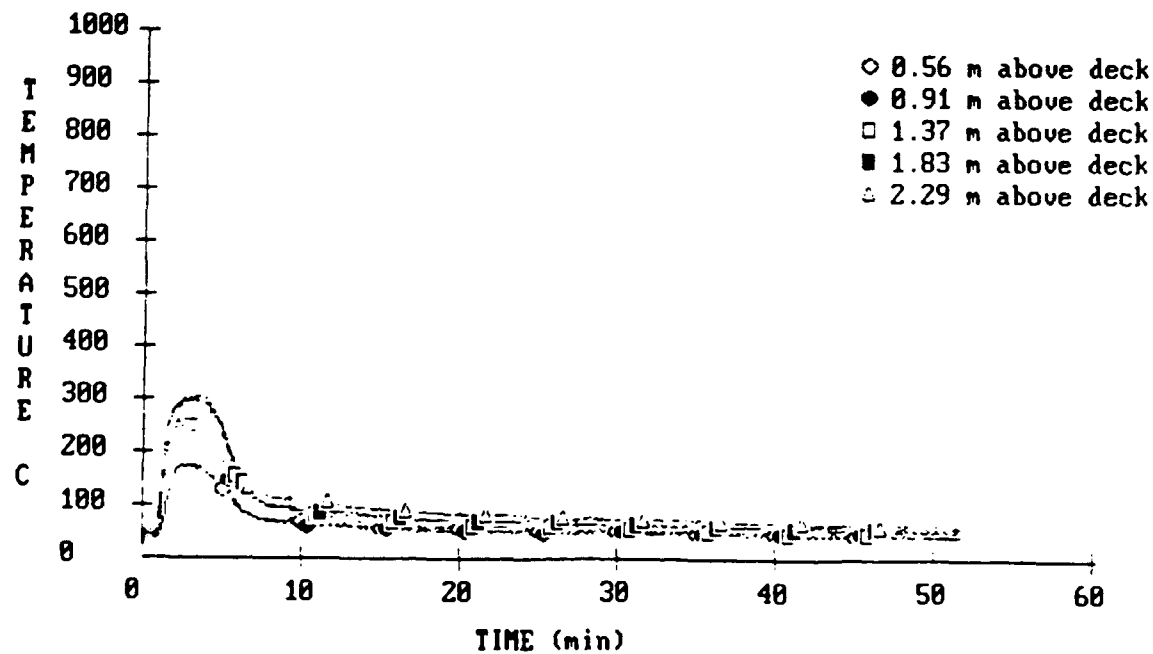


Fig. B-353- Temperature in BERTHING 2 (3-83-6) during Test # 3

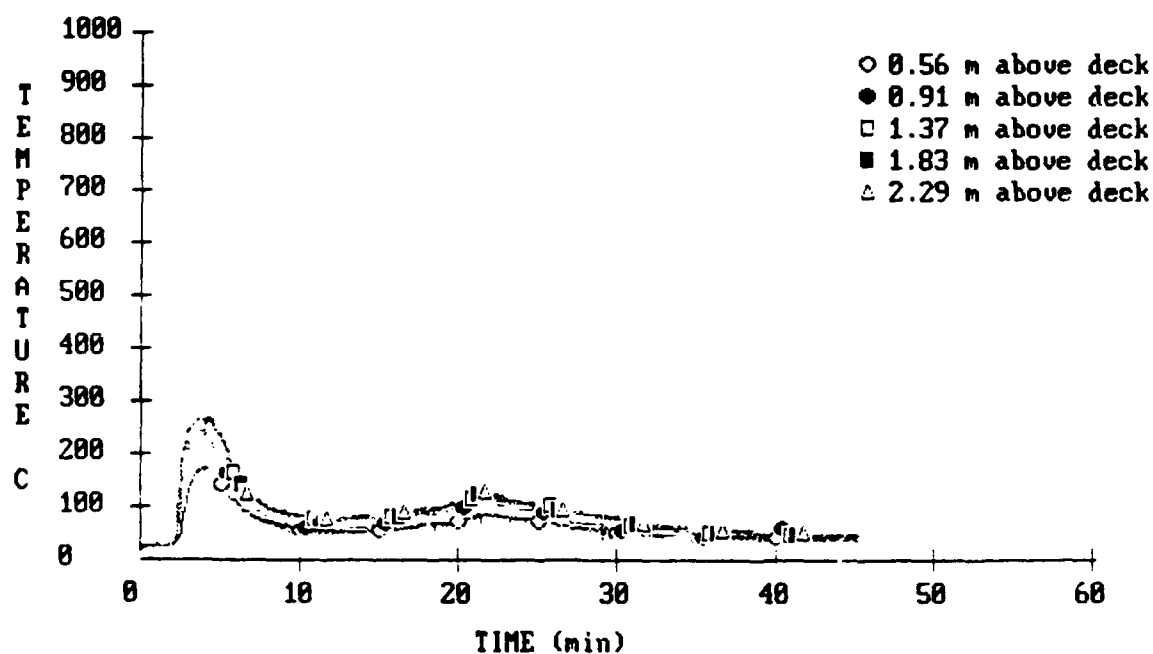


Fig. B-354- Temperature in BERTHING 2 (3-83-6) during Test # 4

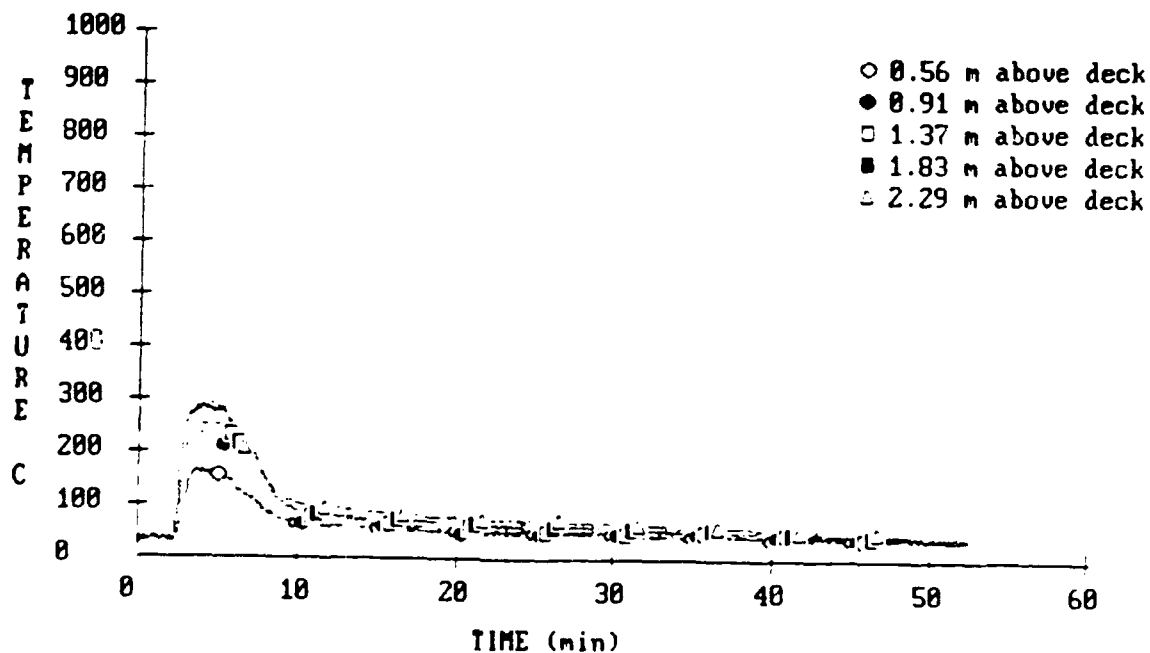


Fig. B-355- Temperature in BERTHING 2 (3-83-6) during Test # 5

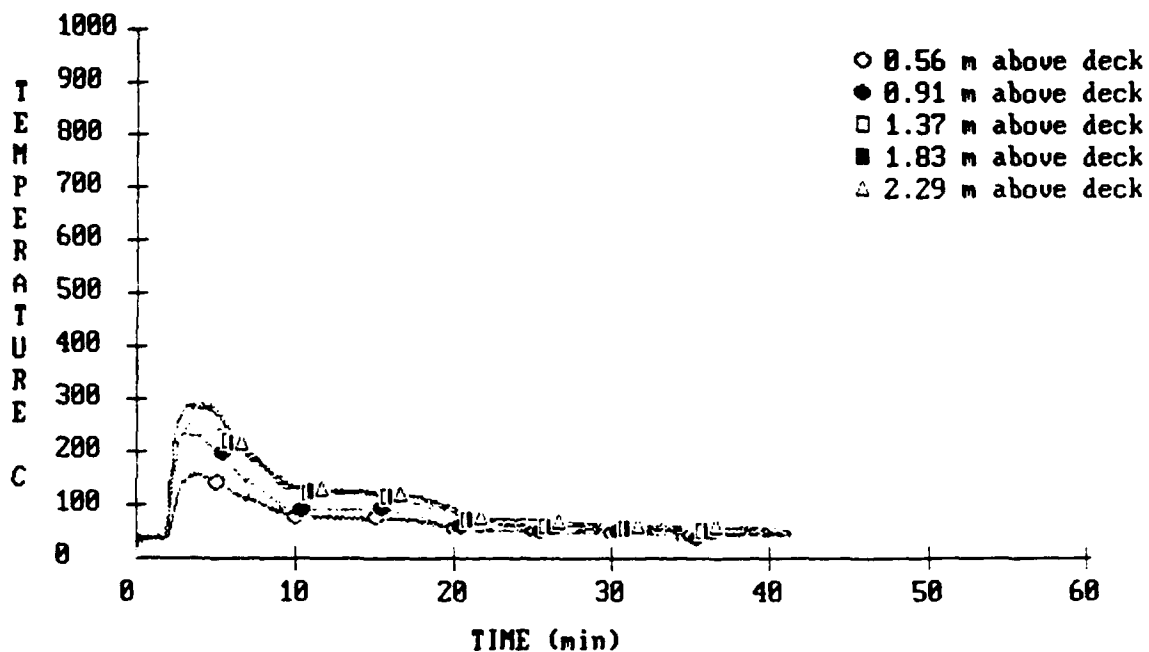


Fig. B-356- Temperature in BERTHING 2 (3-83-6) during Test # 6

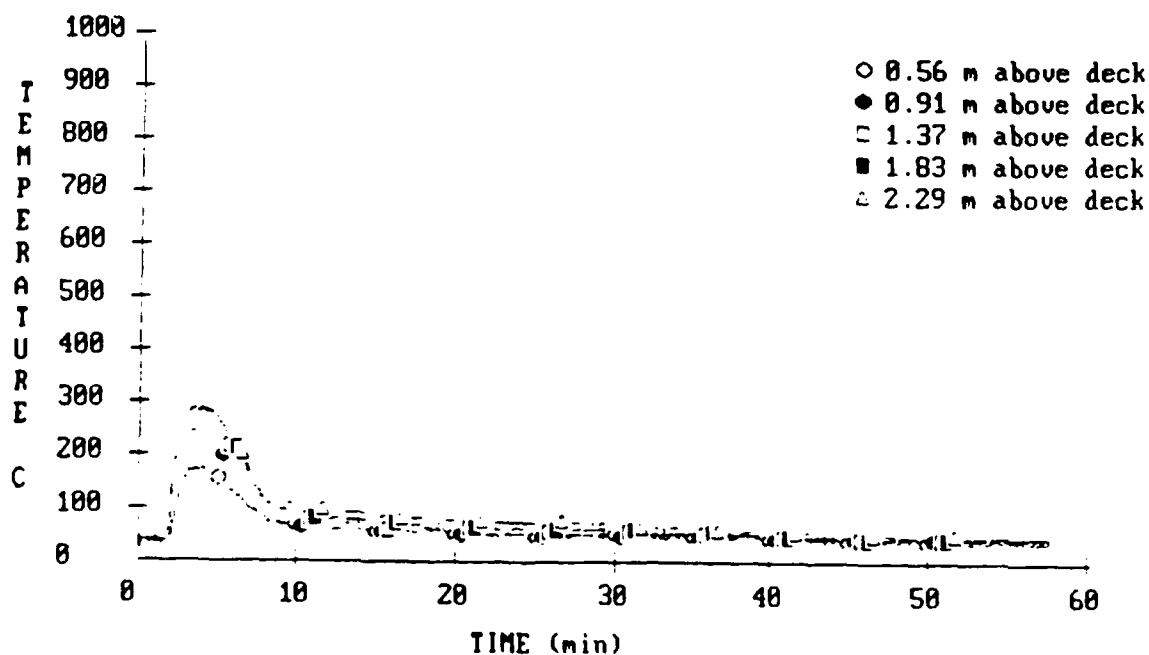


Fig. B-357- Temperature in BERTHING 2 (3-83-6) during Test # 7



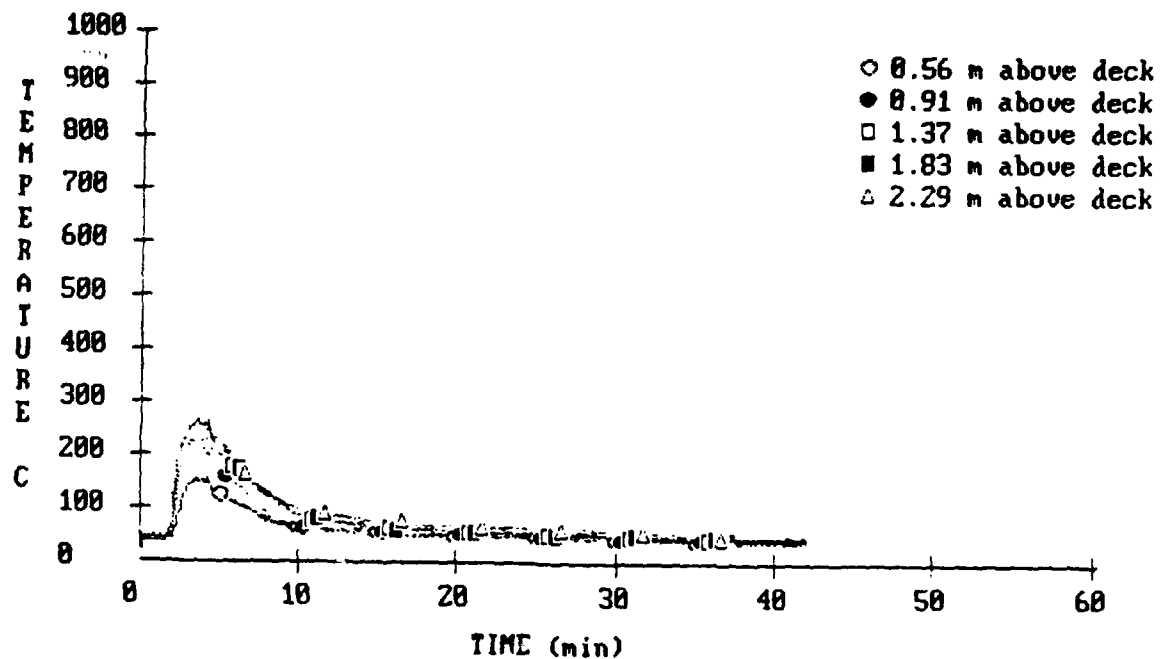


Fig. B-358- Temperature in BERTHING 2 (3-83-6) during Test # 8

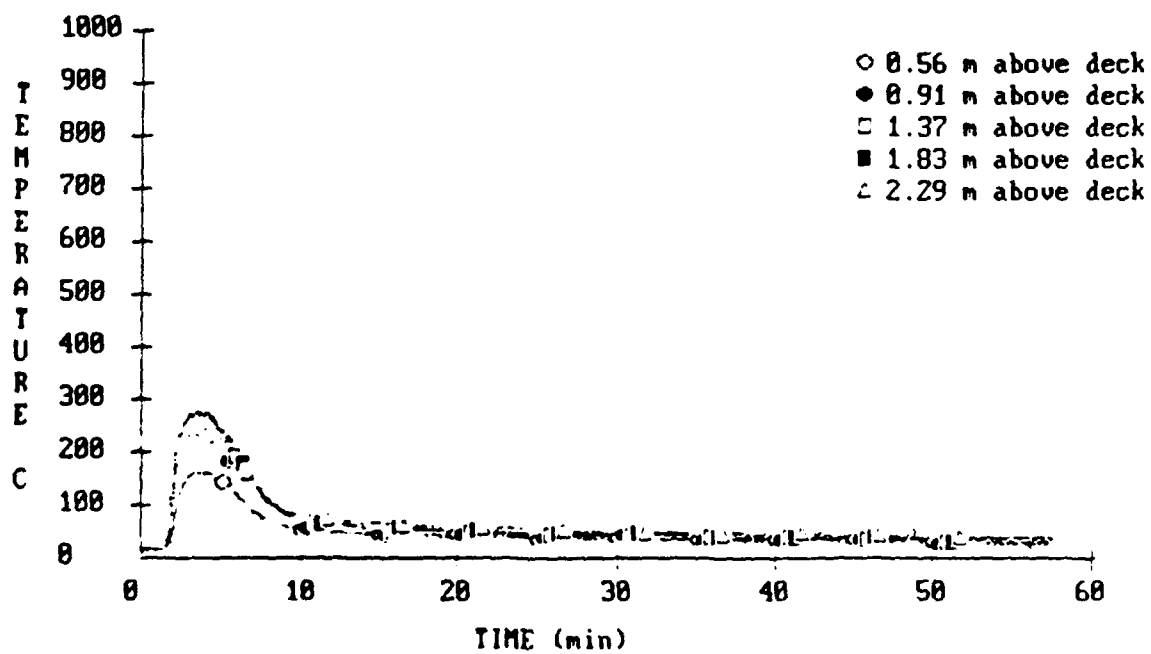


Fig. B-359- Temperature in BERTHING 2 (3-83-6) during Test # 9

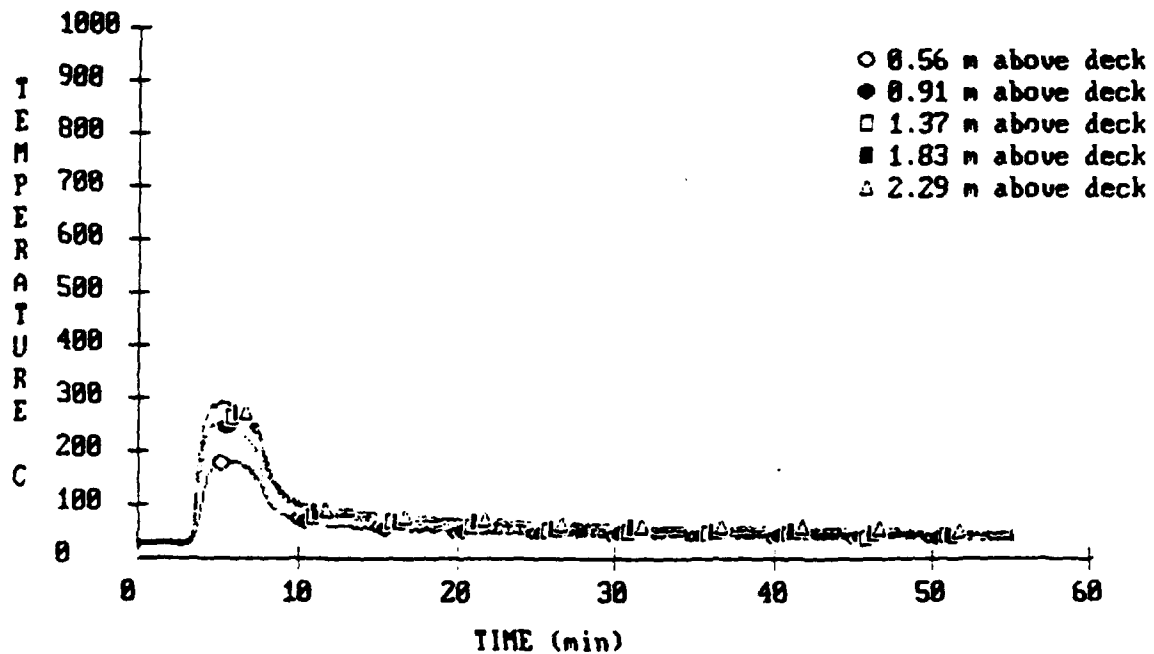


Fig. B-360- Temperature in BERTHING 2 (3-83-6) during Test # 10

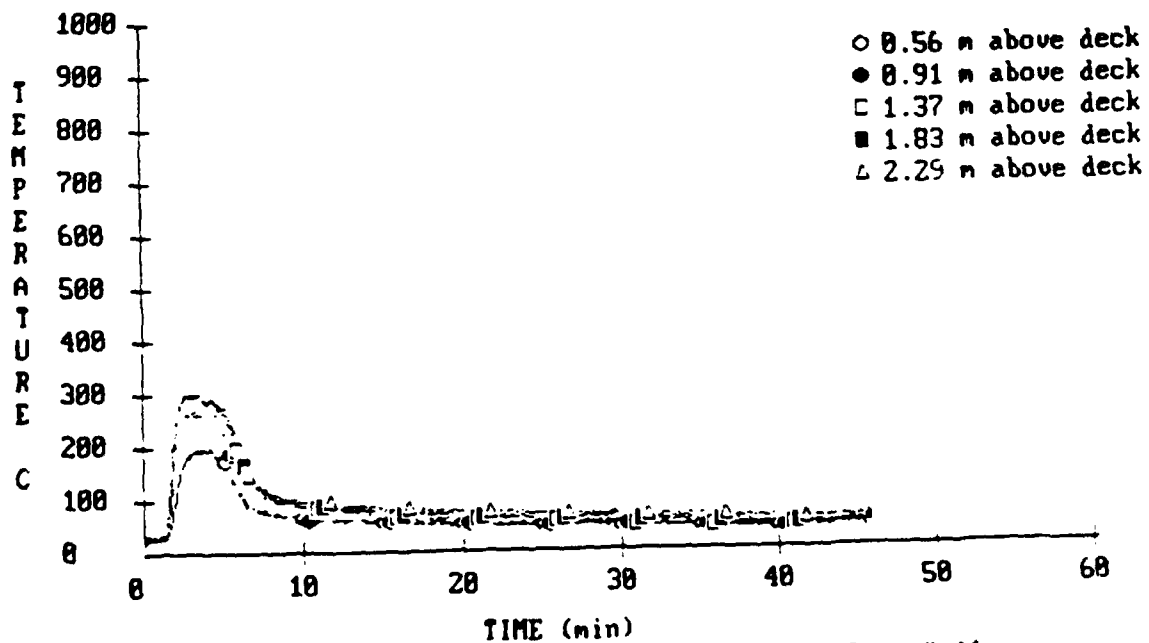


Fig. B-361- Temperature in BERTHING 2 (3-83-6) during Test # 11

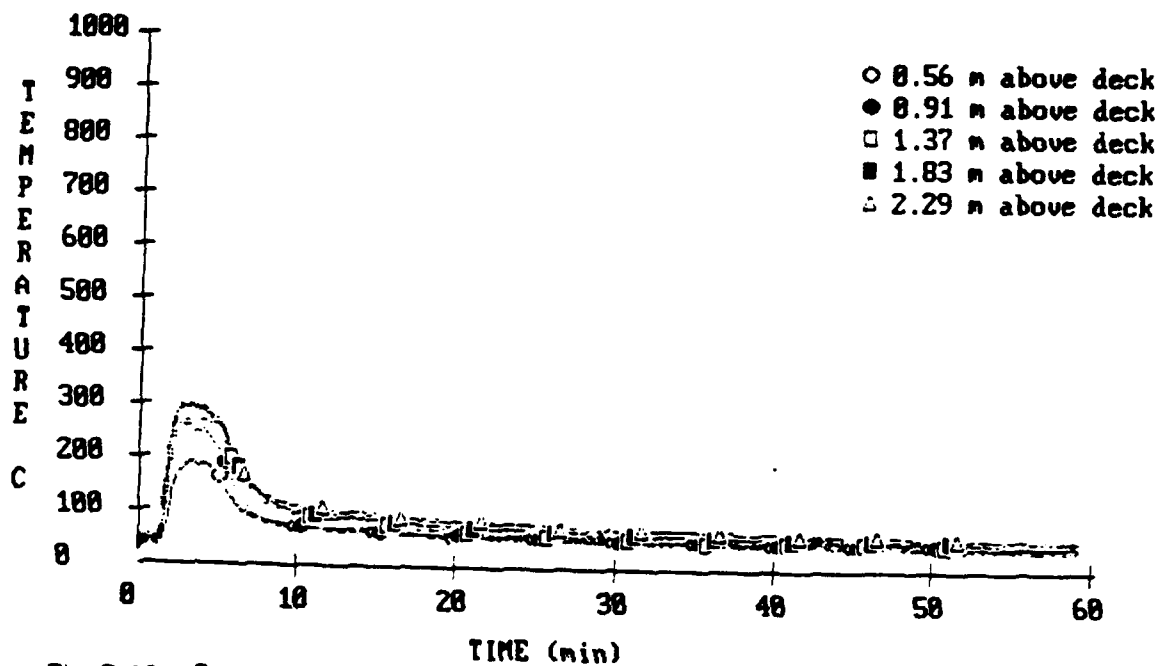


Fig. B-362- Temperature in BERTHING 2 (3-83-6) during Test # 12

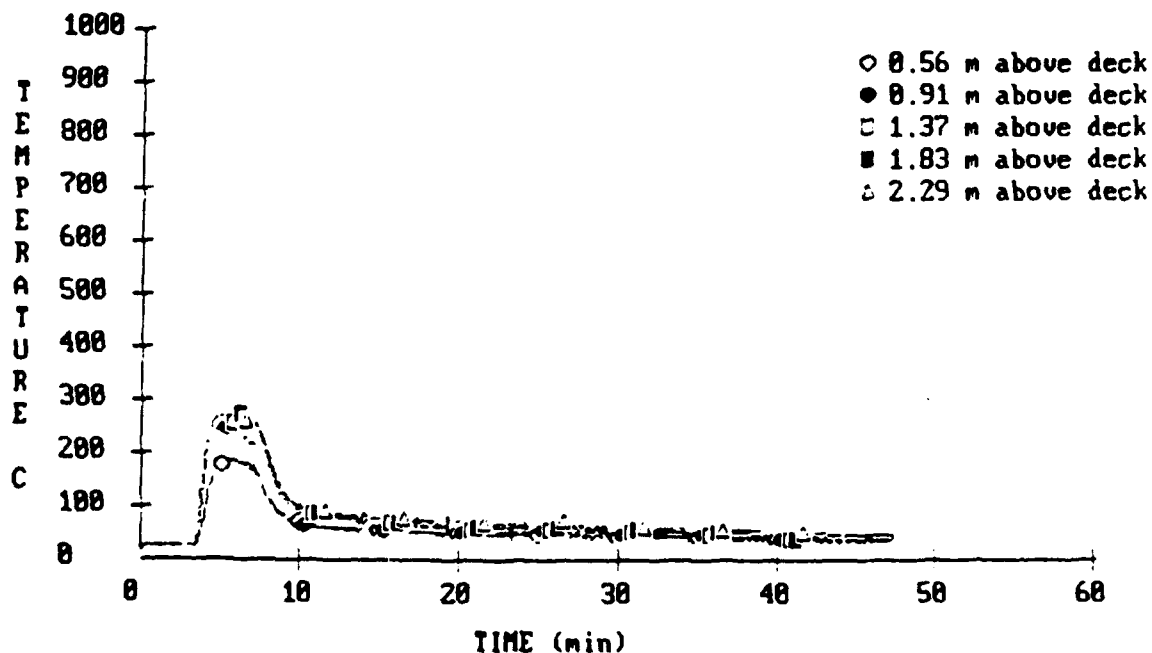


Fig. B-363- Temperature in BERTHING 2 (3-83-6) during Test # 13

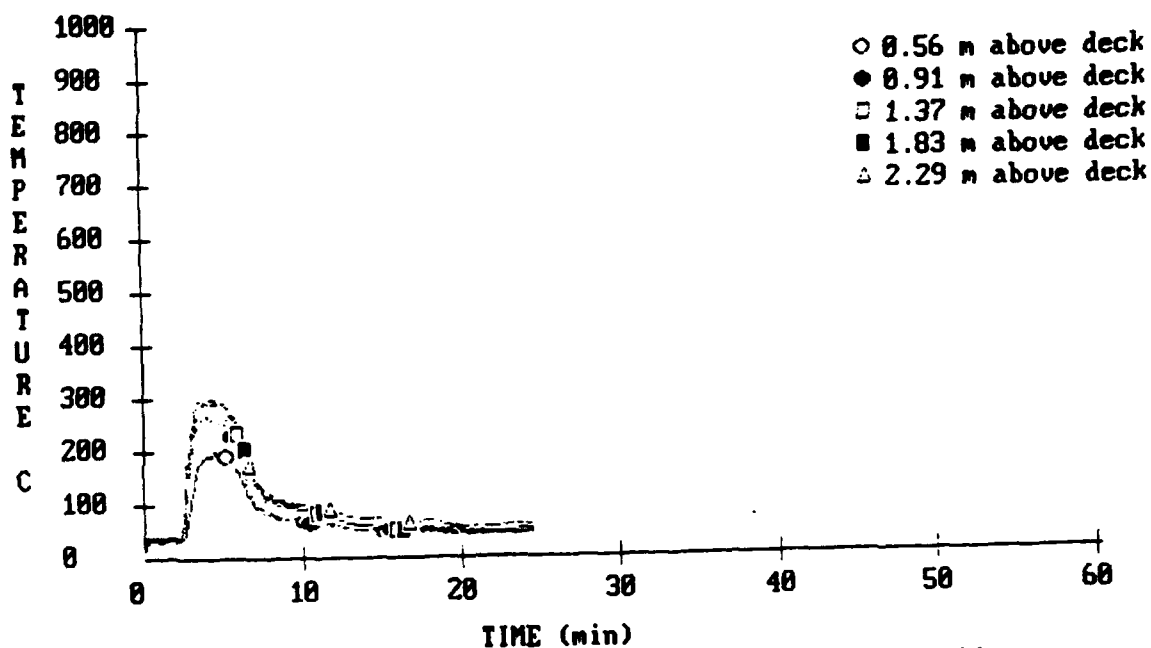


Fig. B-364- Temperature in BERTHING 2 (3-83-6) during Test # 14

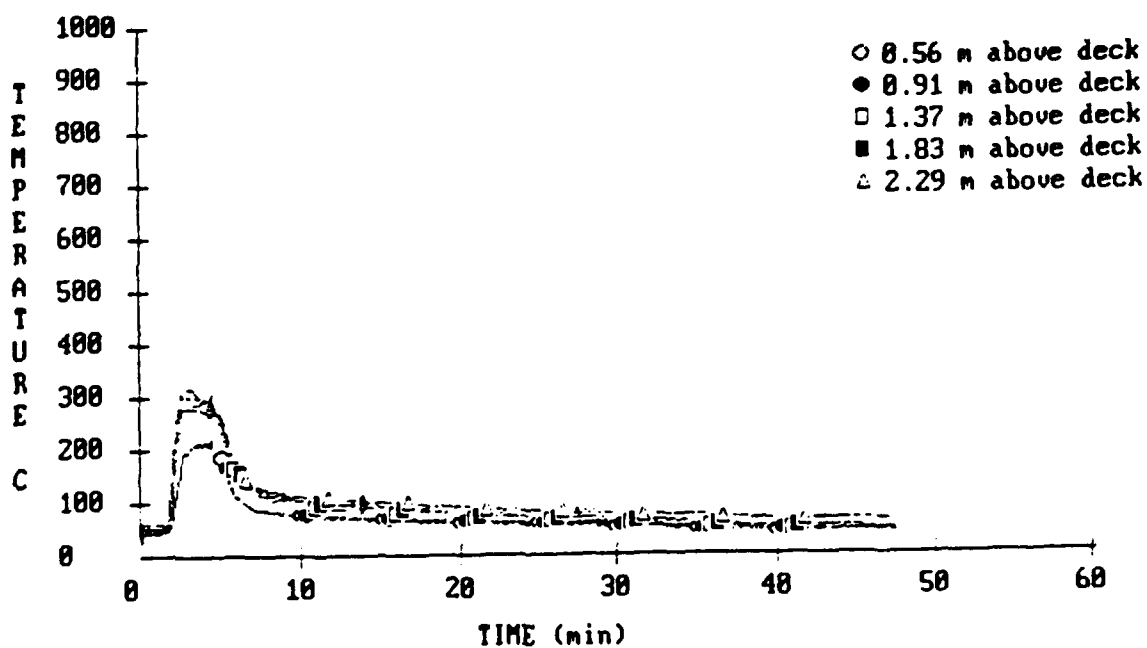


Fig. B-365- Temperature in BERTHING 2 (3-83-6) during Test # 15

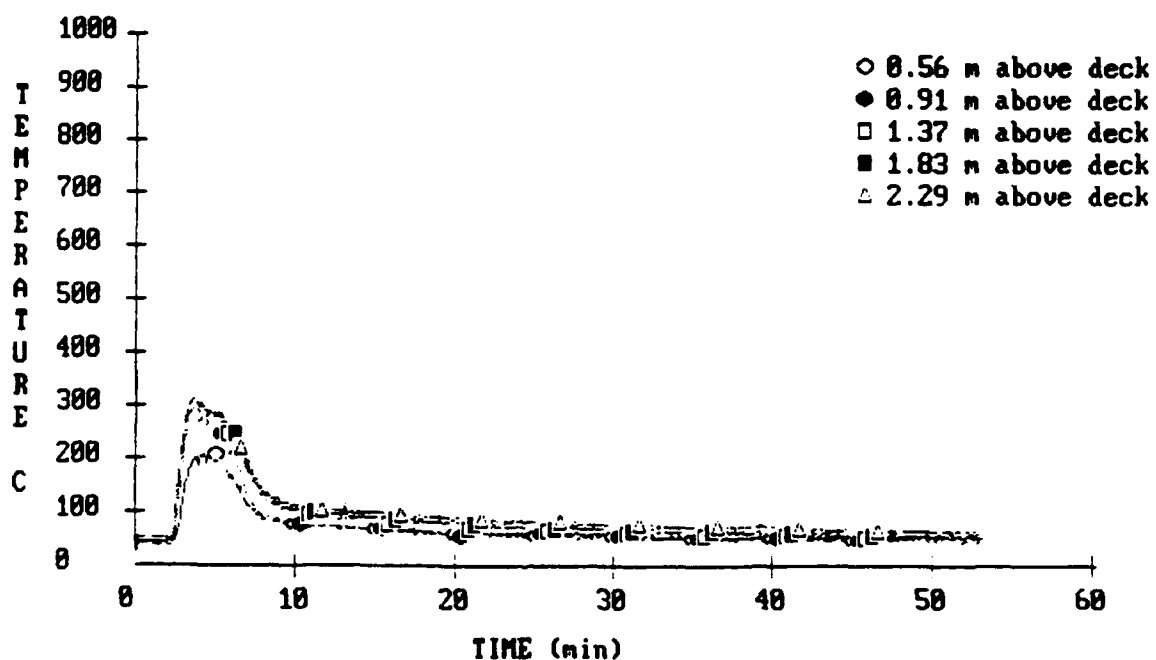


Fig. B-366- Temperature in BERTHING 2 (3-83-6) during Test # 16

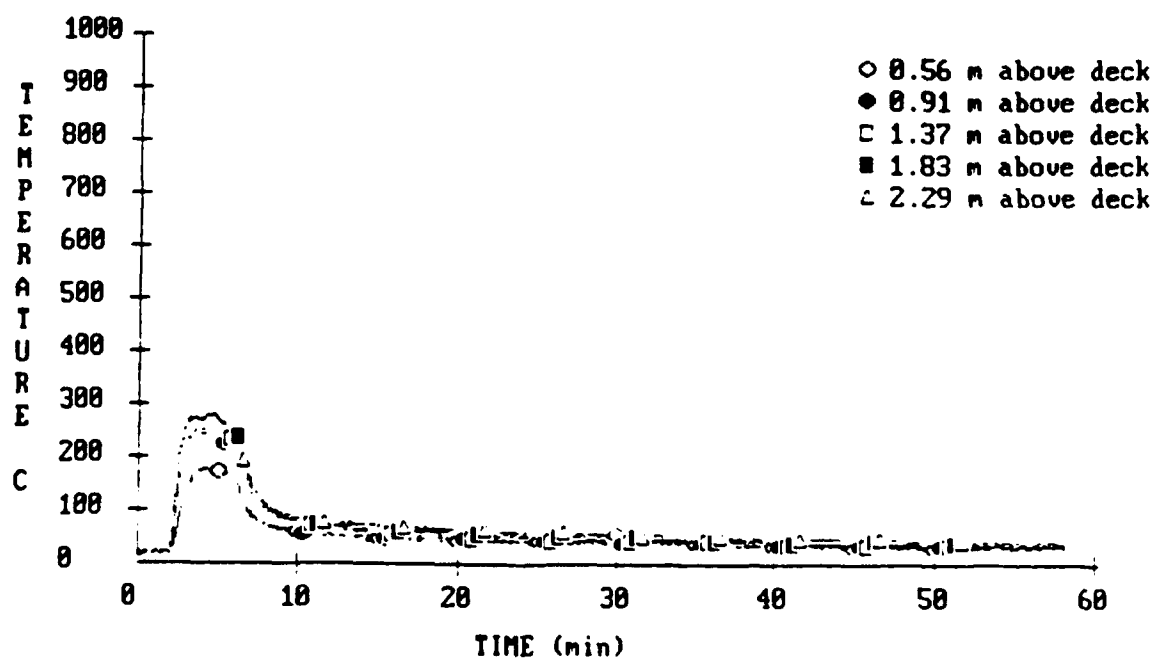


Fig. B-367- Temperature in BERTHING 2 (3-83-6) during Test # 17

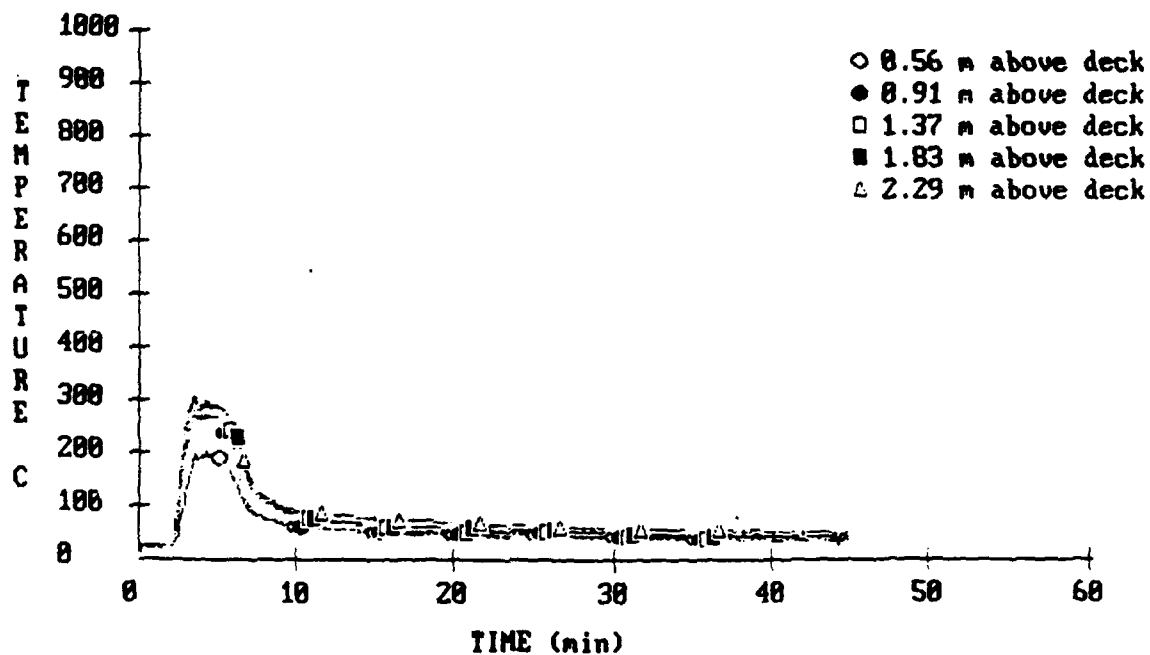


Fig. B-368- Temperature in BERTHING 2 (3-83-6) during Test # 18

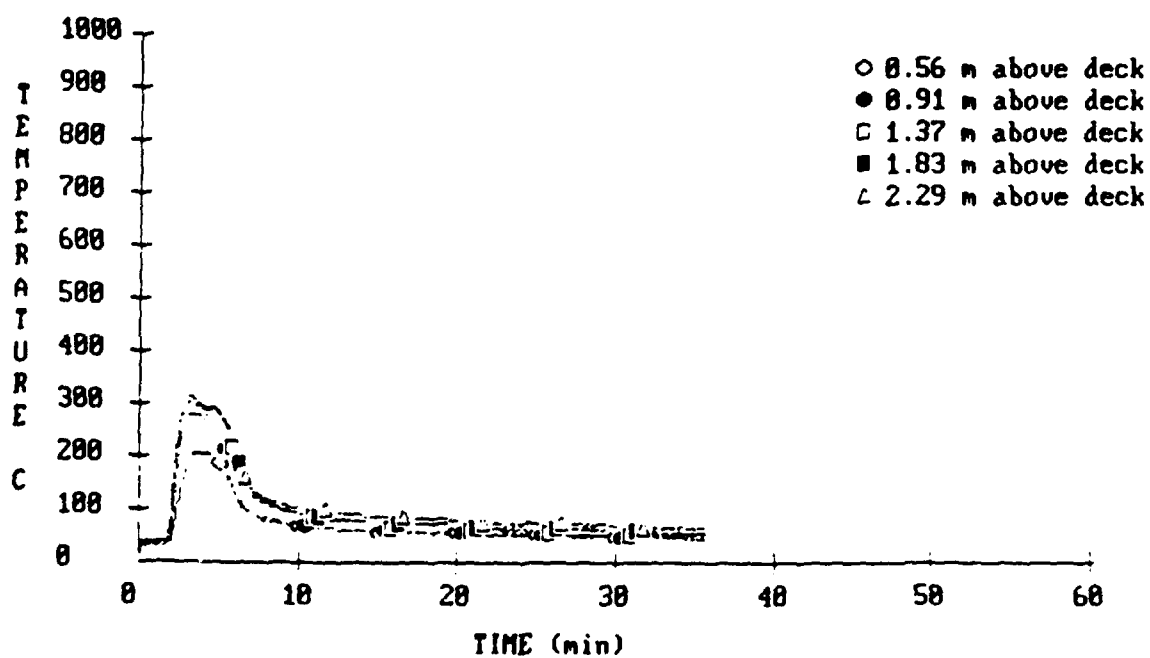


Fig. B-369- Temperature in BERTHING 2 (3-83-6) during Test # 19

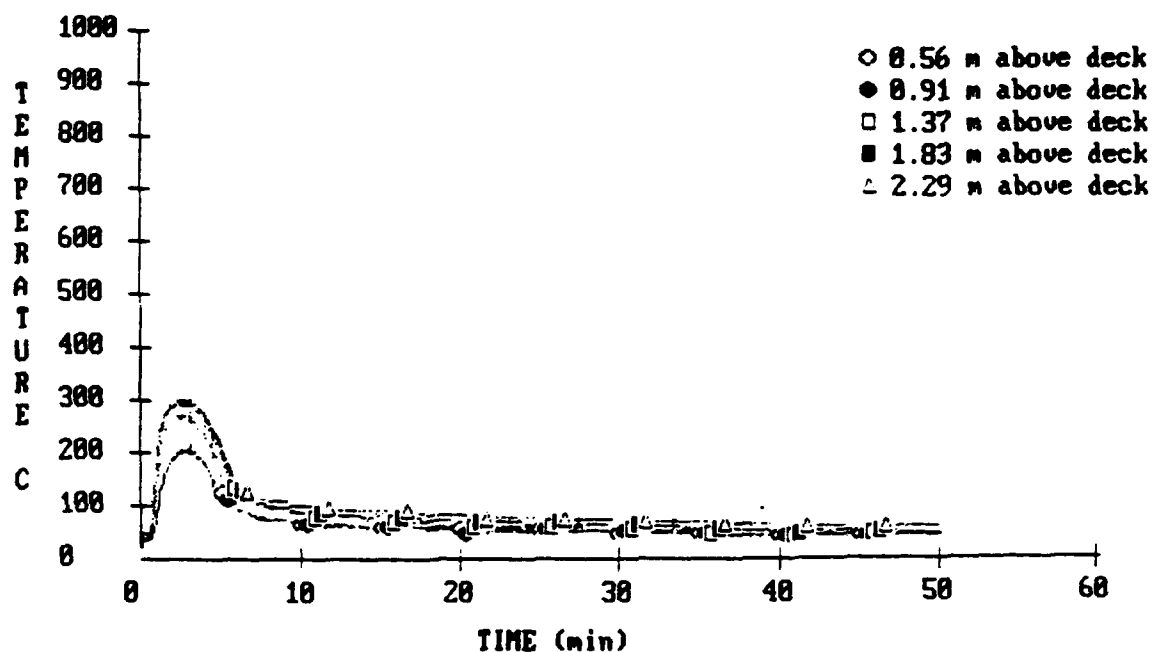


Fig. B-370- Temperature in BERTHING 2 (3-83-6) during Test # 20

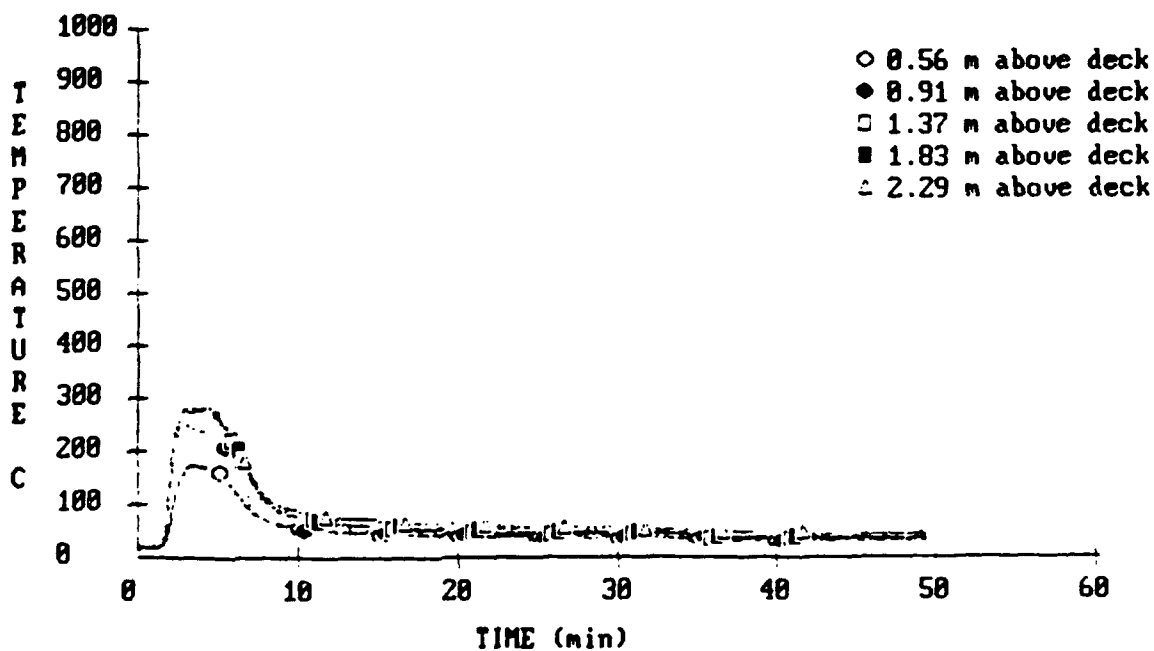


Fig. B-371- Temperature in BERTHING 2 (3-83-6) during Test # 21

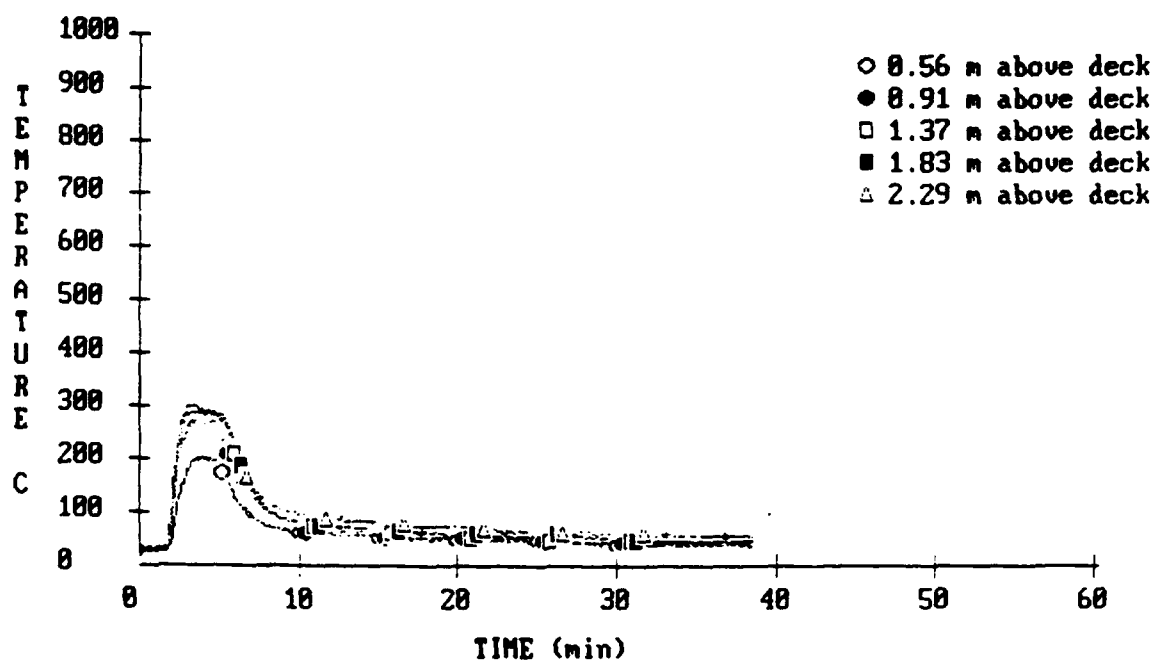


Fig. B-372- Temperature in BERTHING 2 (3-83-6) during Test # 22

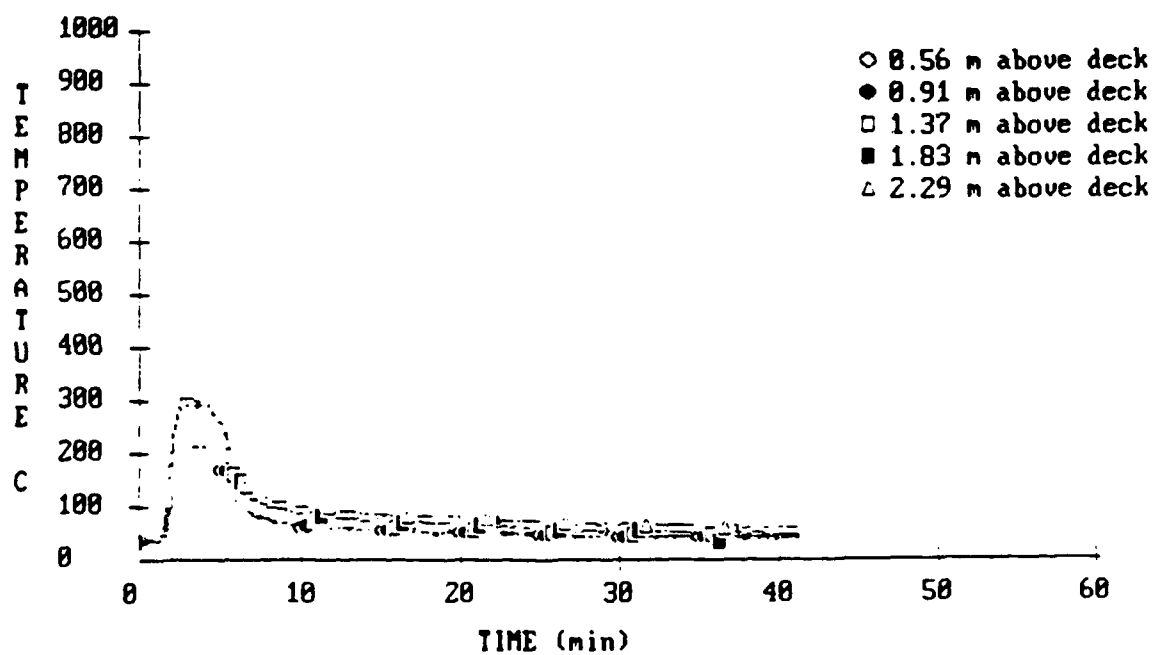


Fig. B-373- Temperature in BERTHING 2 (3-83-6) during Test # 23



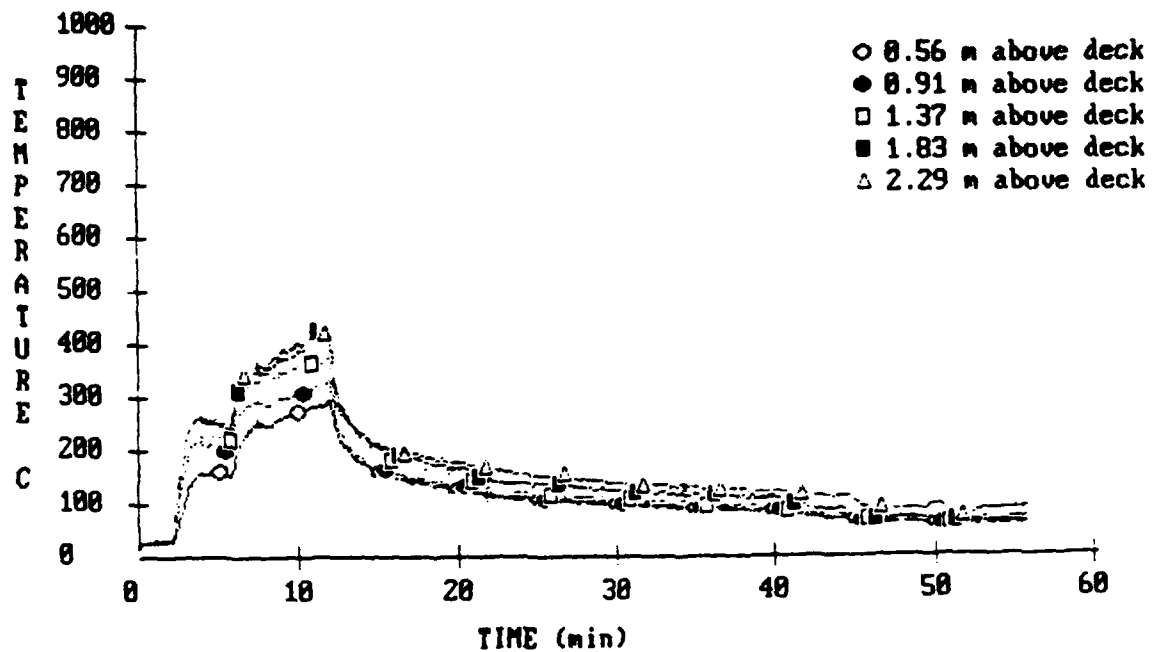


Fig. B-374- Temperature in BERTHING 2 (3-83-6) during Test # 24

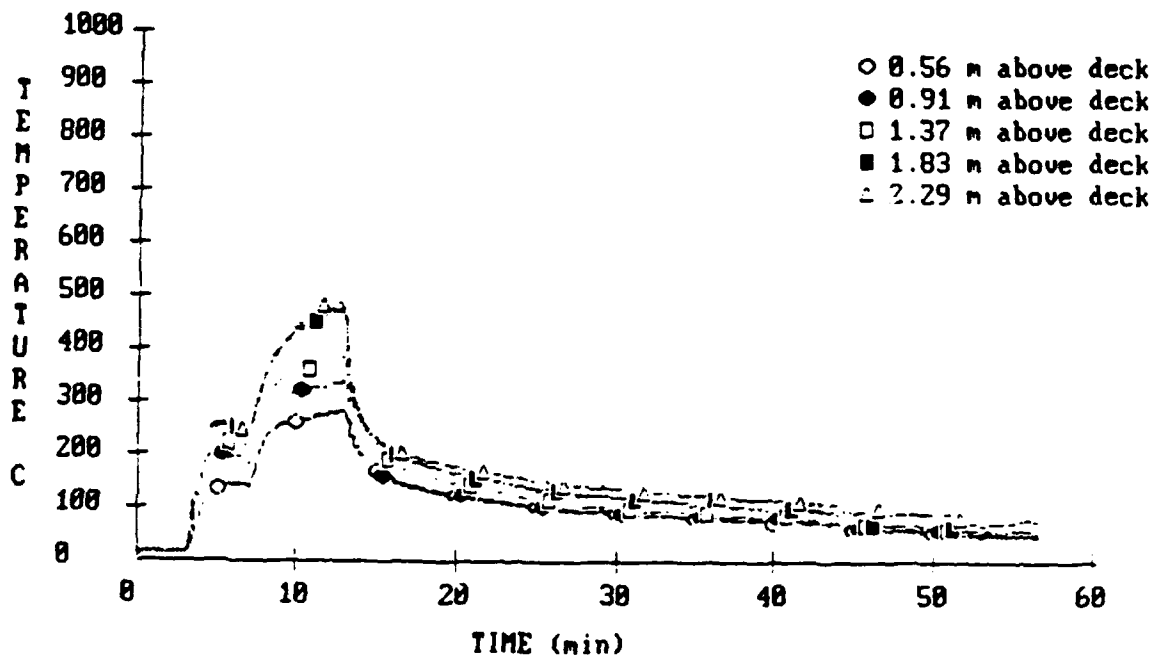


Fig. B-375- Temperature in BERTHING 2 (3-83-6) during Test # 25

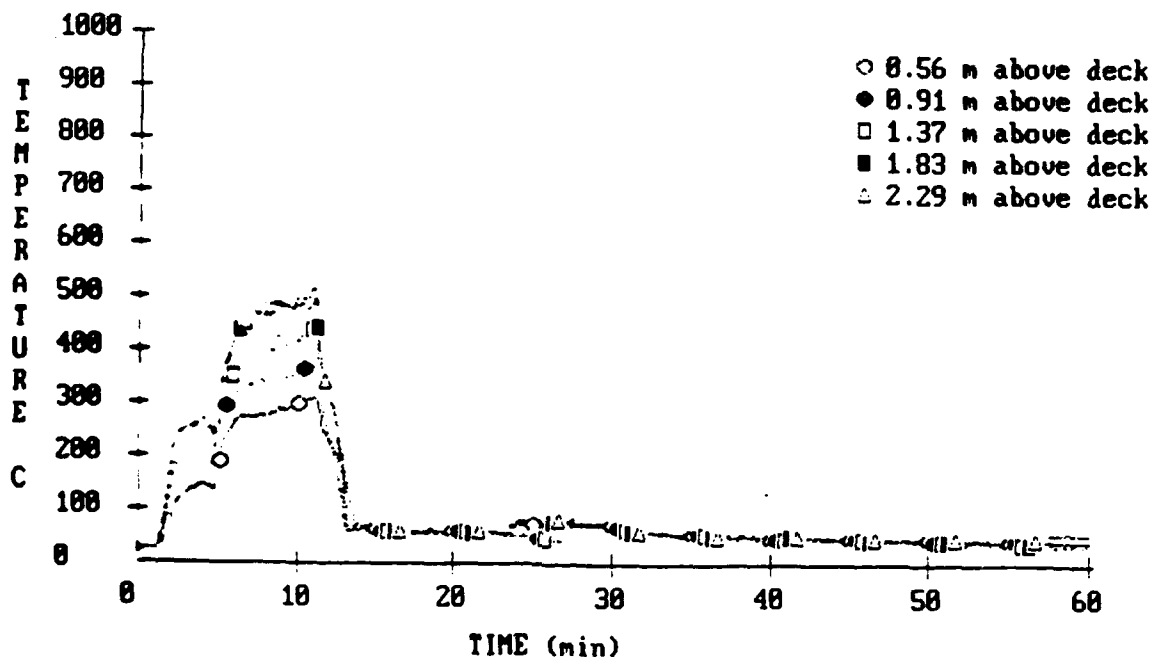


Fig. B-376- Temperature in BERTHING 2 (3-83-6) during Test # 26

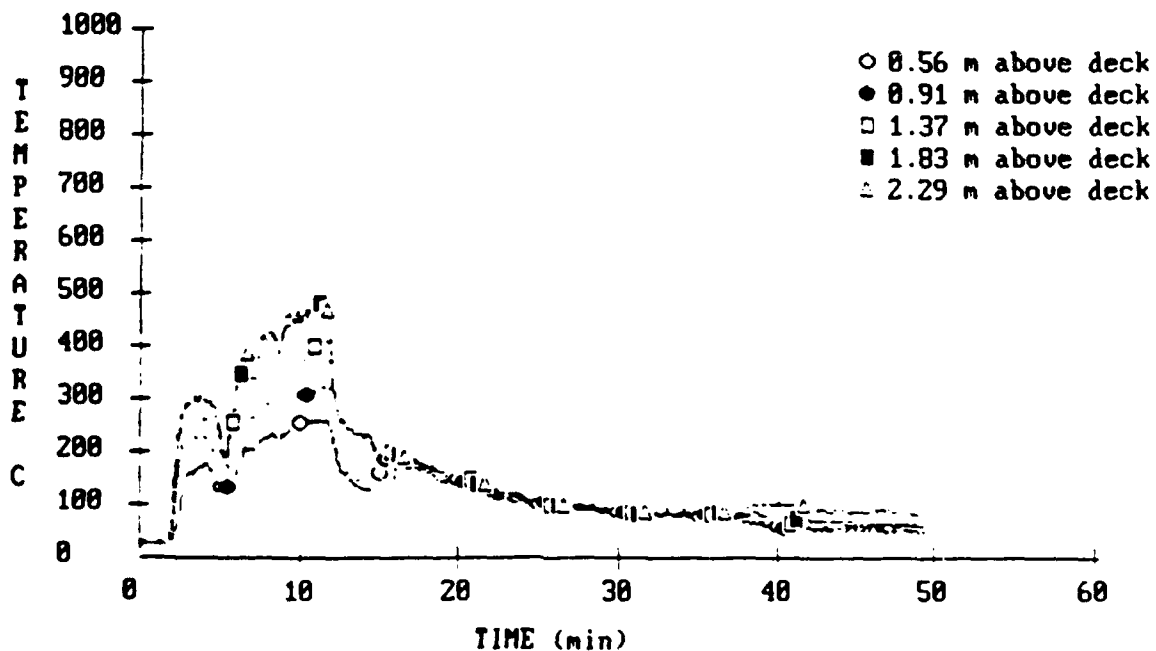


Fig. B-377- Temperature in BERTHING 2 (3-83-6) during Test # 27

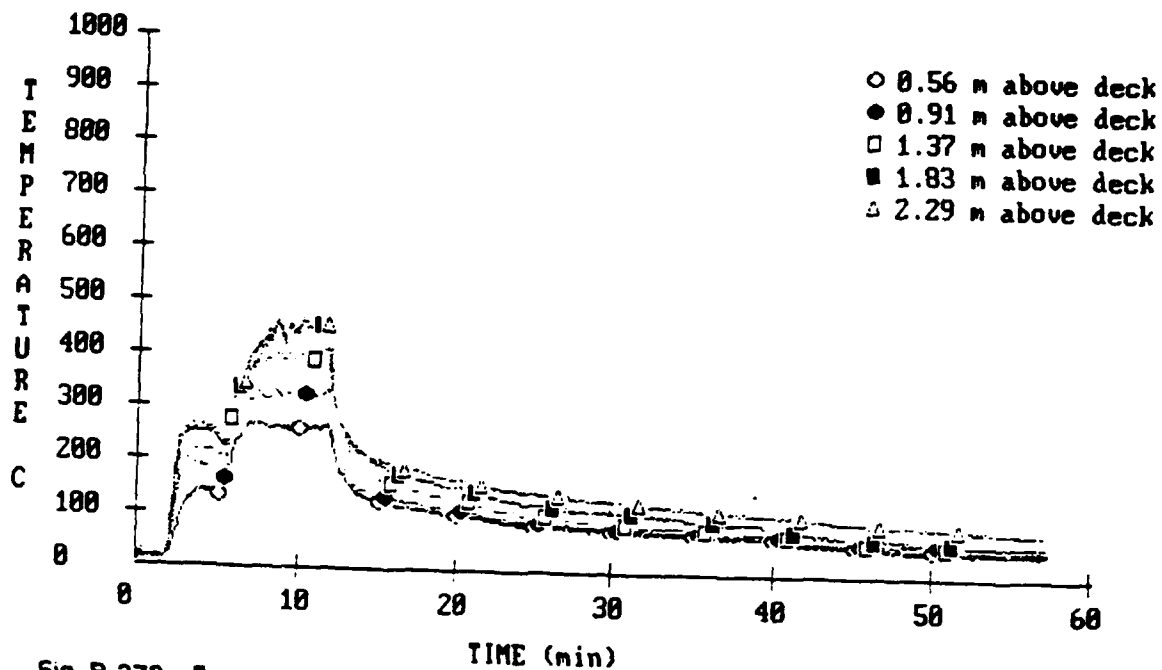


Fig. B-378- Temperature in BERTHING 2 (3-83-6) during Test # 28

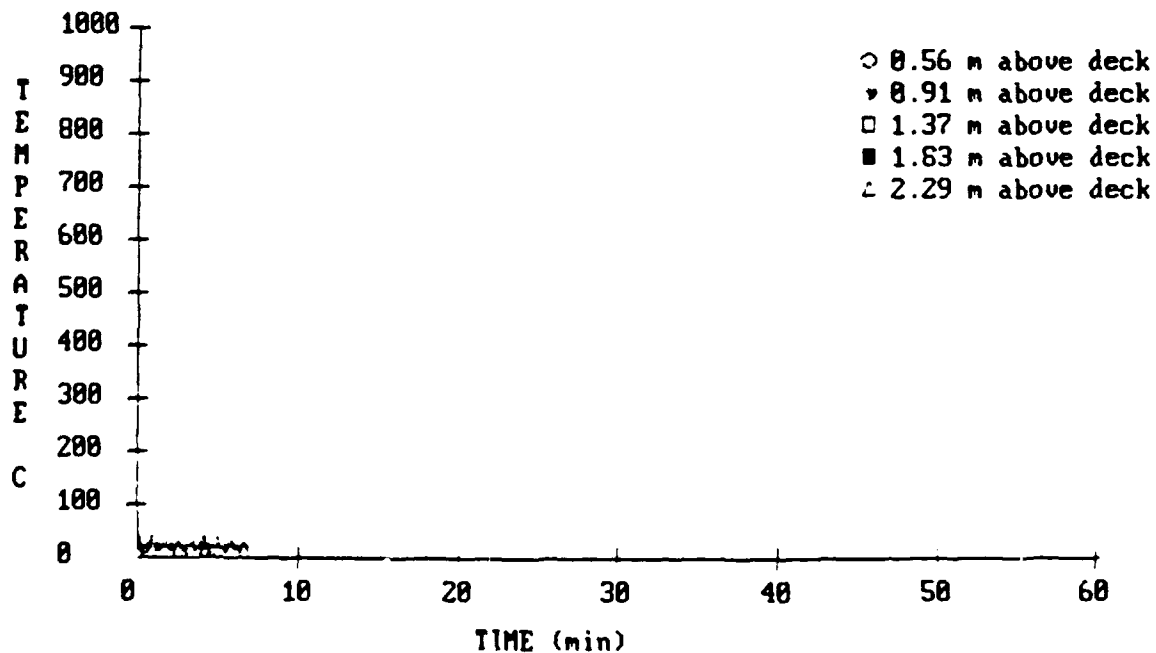


Fig. B-379- Temperature in BERTHING 2 (3-83-6) during Test # 29

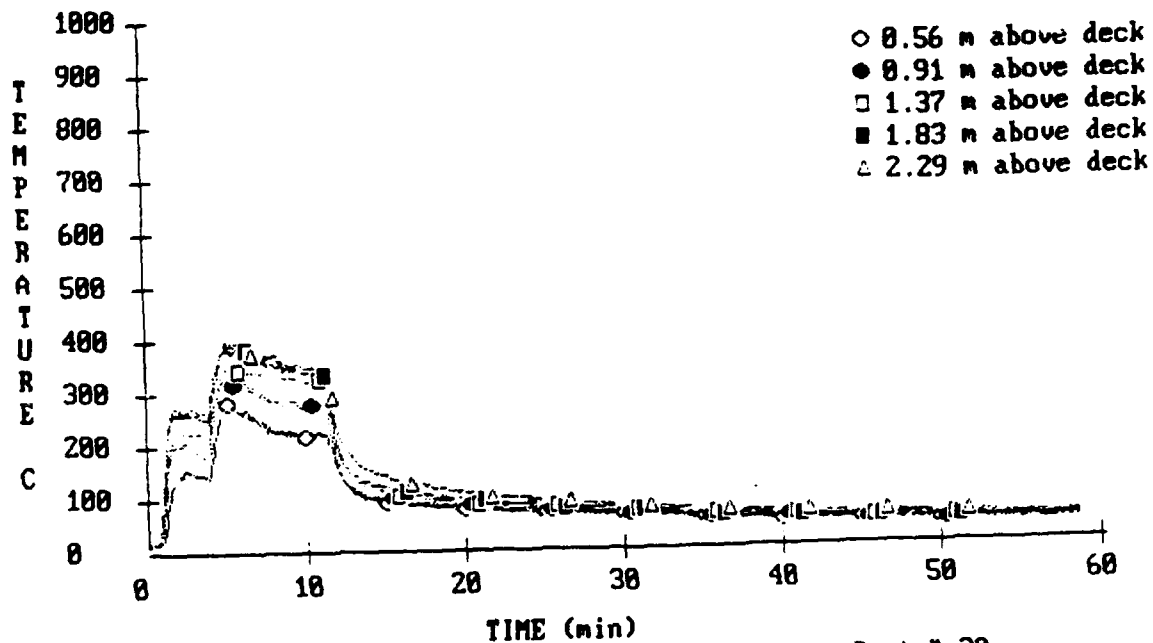


Fig. B-380- Temperature in BERTHING 2 (3-83-6) during Test # 30

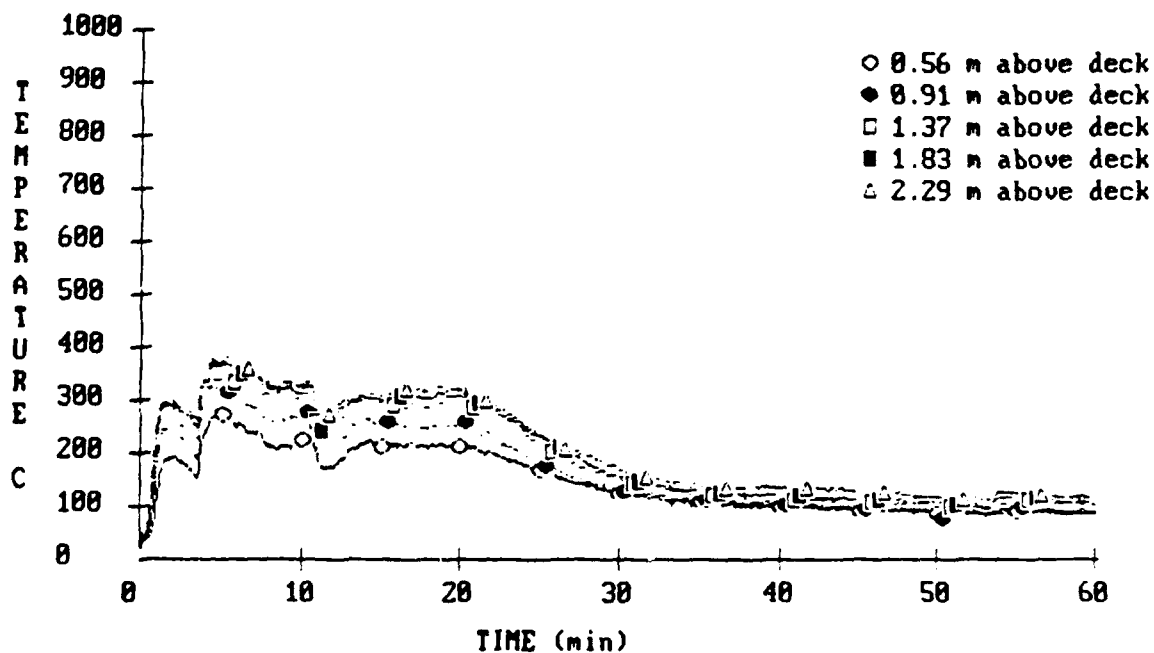


Fig. B-381- Temperature in BERTHING 2 (3-83-6) during Test # 31

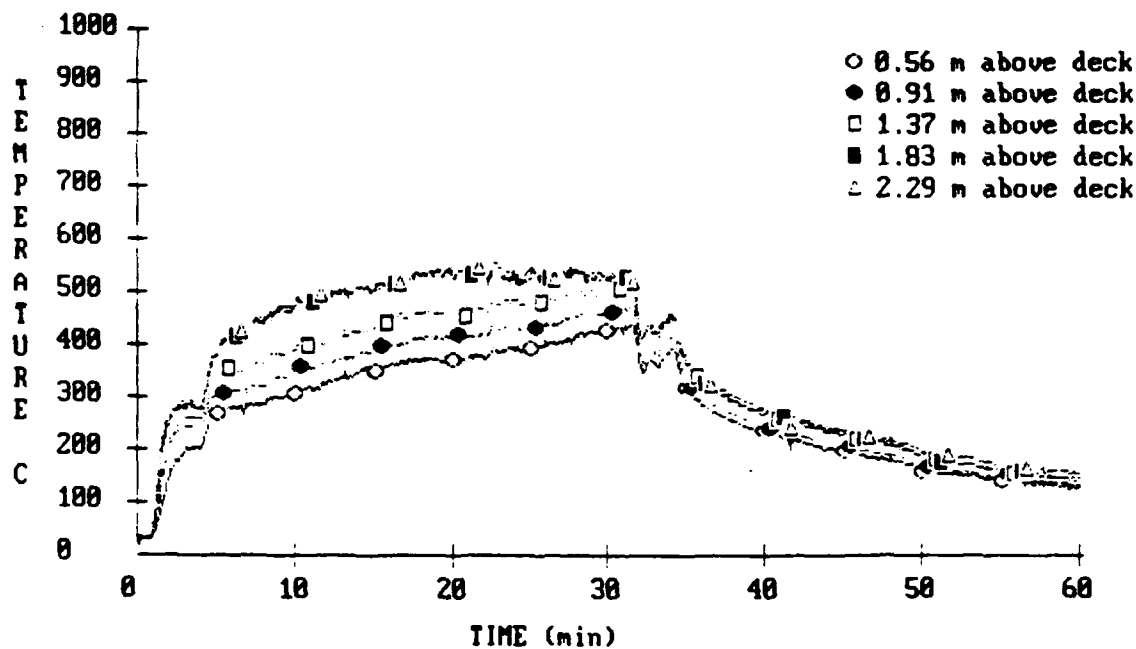


Fig. B-382- Temperature in BERTHING 2 (3-83-6) during Test # 32

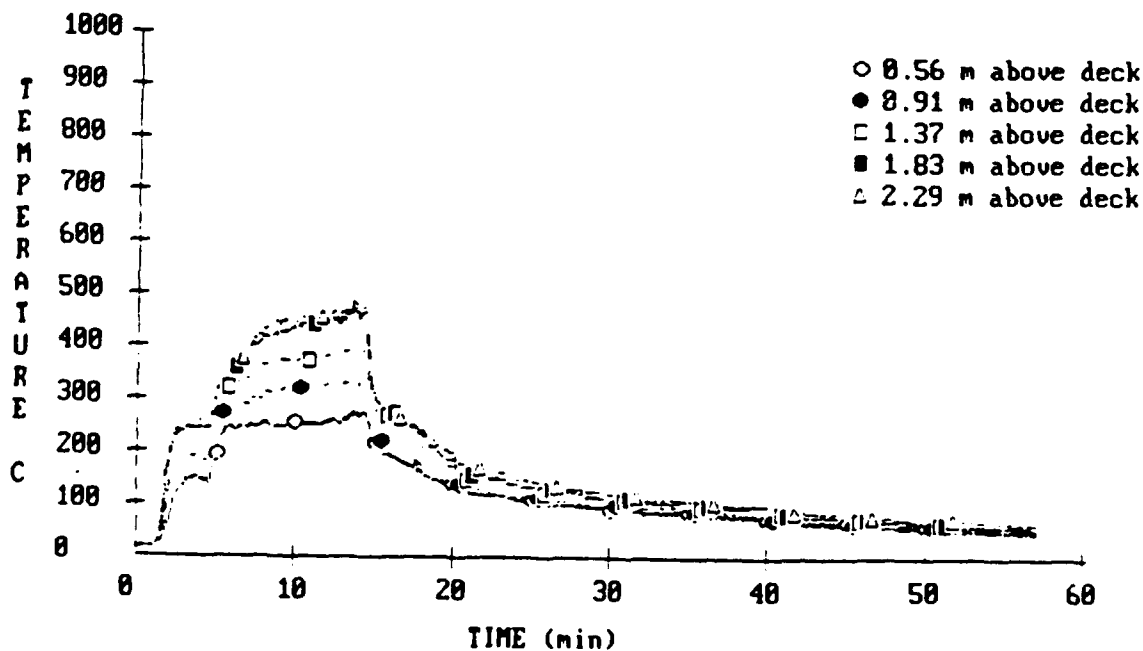


Fig. B-383- Temperature in BERTHING 2 (3-83-6) during Test # 33

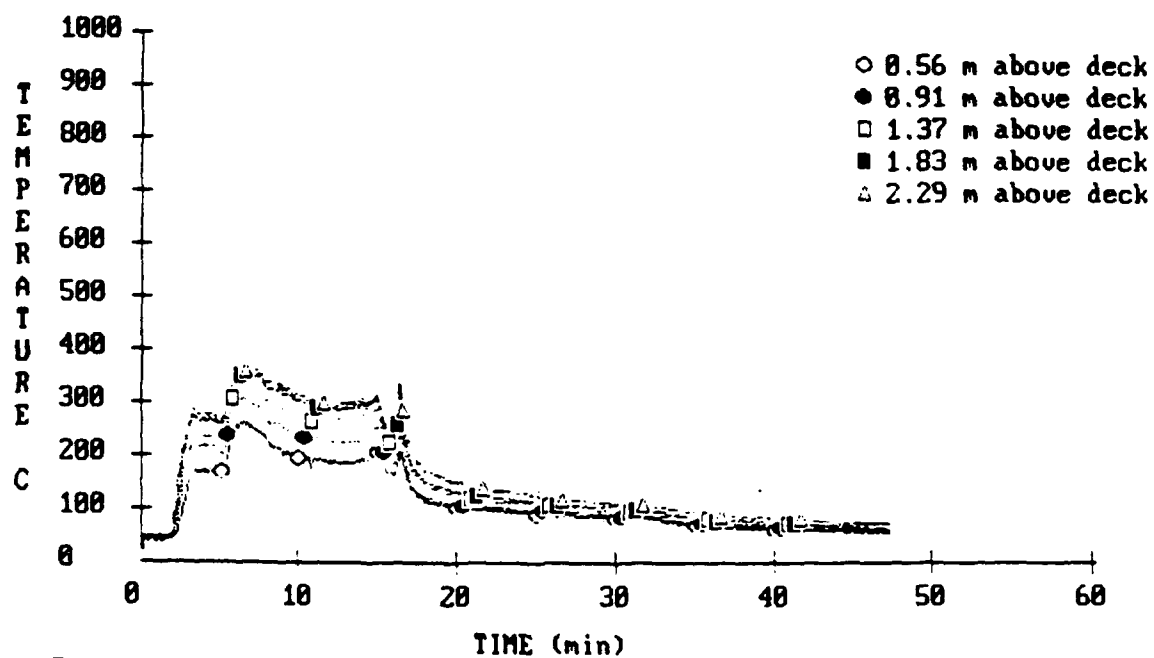


Fig. B-384- Temperature in BERTHING 2 (3-83-6) during Test # 34

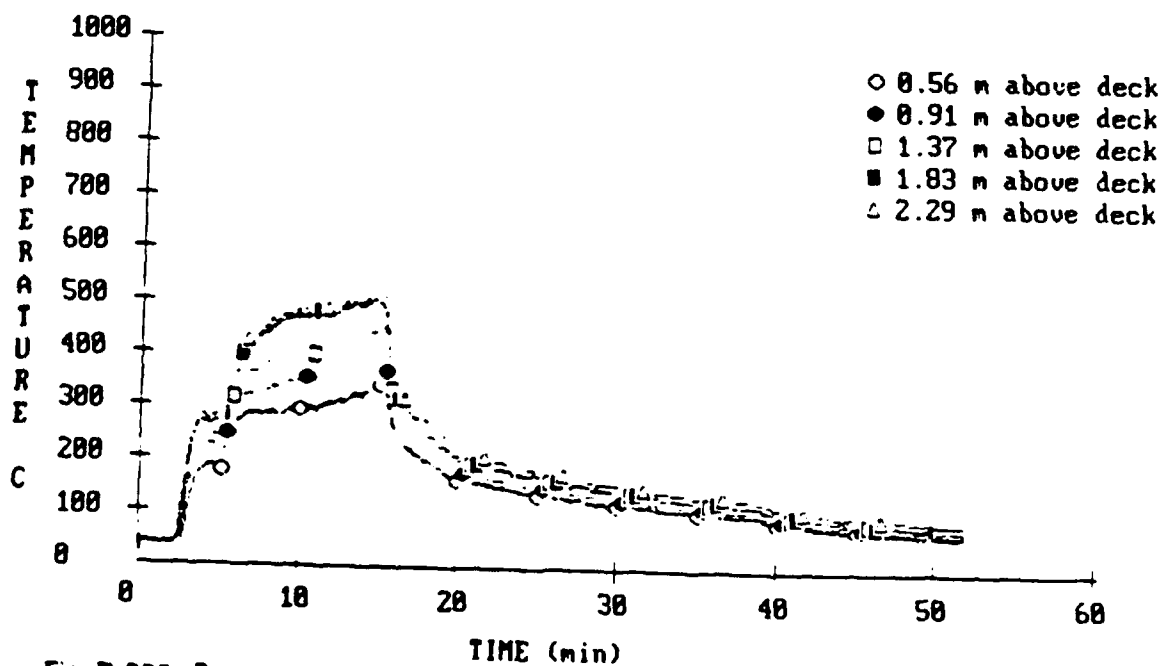


Fig. B-385- Temperature in BERTHING 2 (3-83-6) during Test # 35

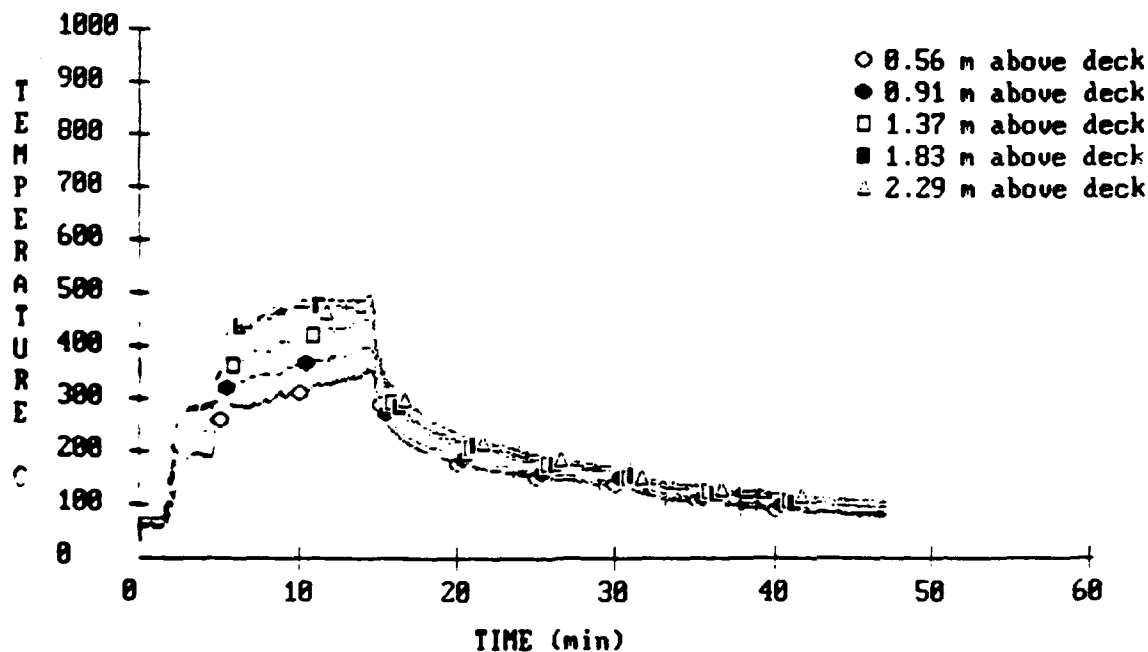


Fig. B-386- Temperature in BERTHING 2 (3-83-6) during Test # 36

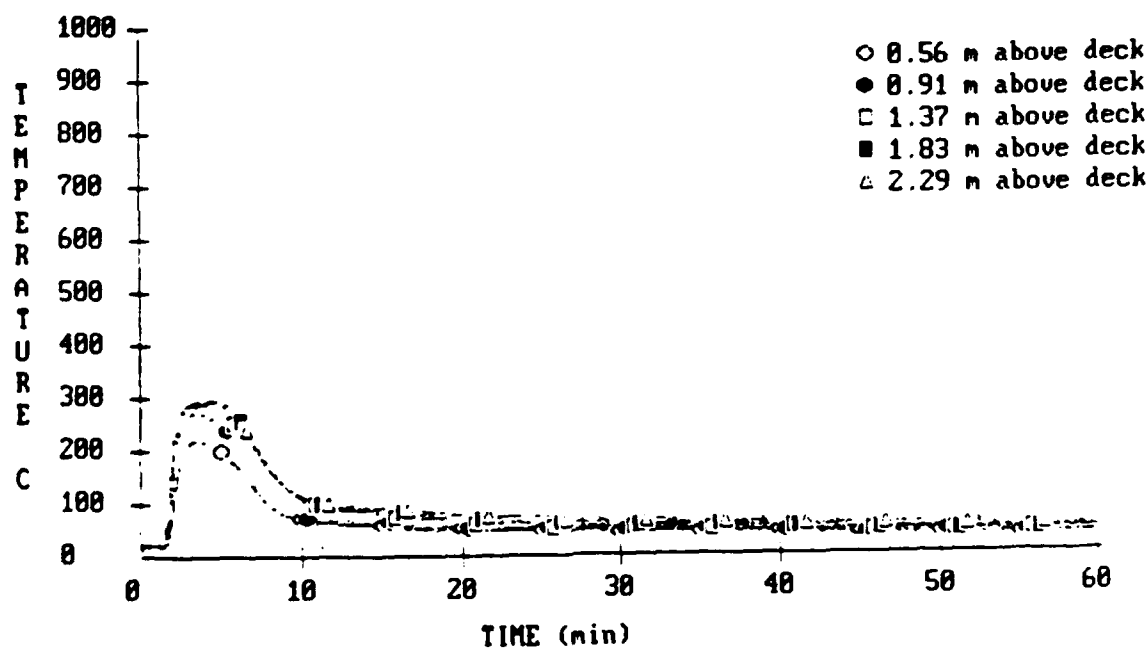


Fig. B-387- Temperature in BERTHING 2 (3-83-6) during Test # 37

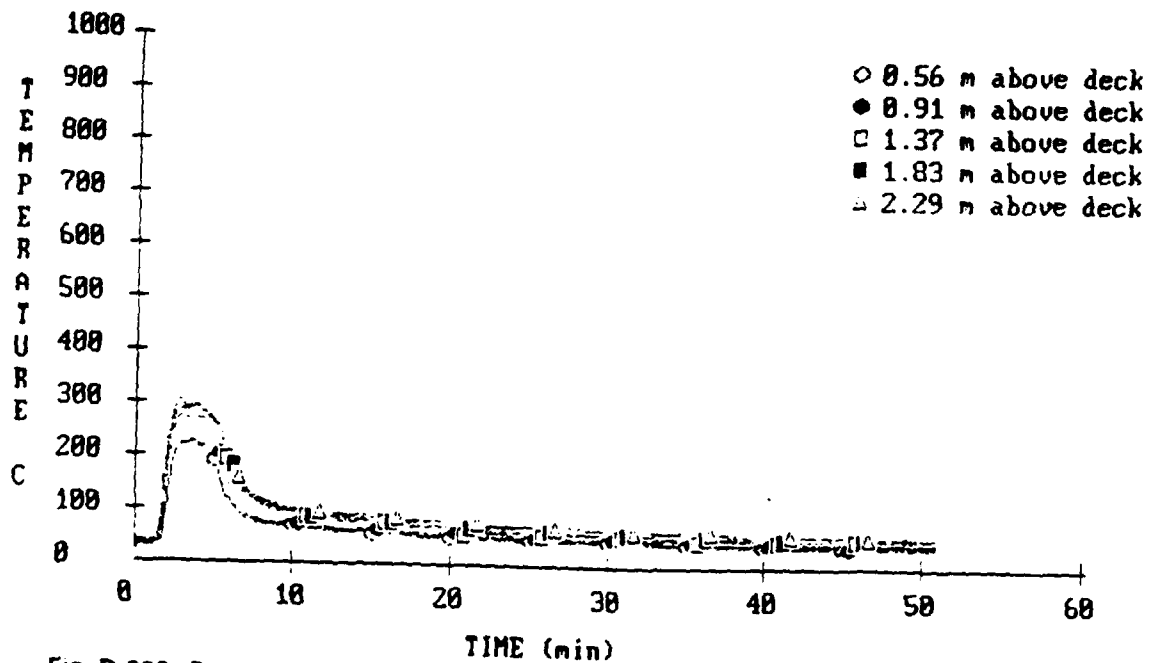


Fig. B-388- Temperature in BERTHING 2 (3-83-6) during Test # 38

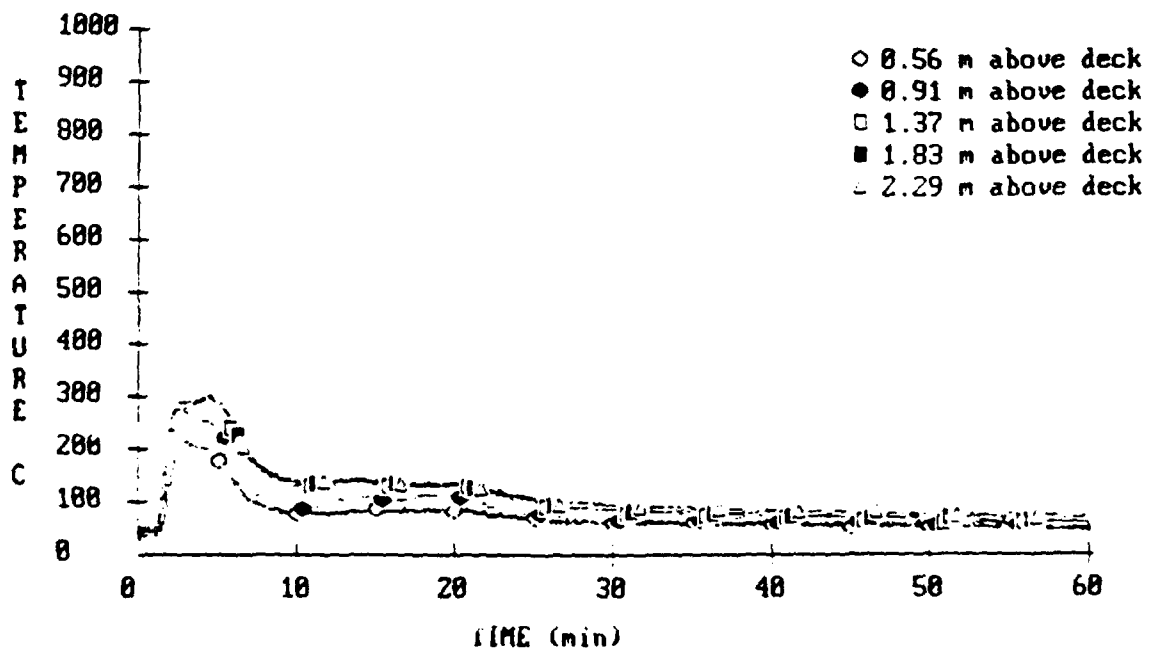


Fig. B-389- Temperature in BERTHING 2 (3-83-6) during Test # 39



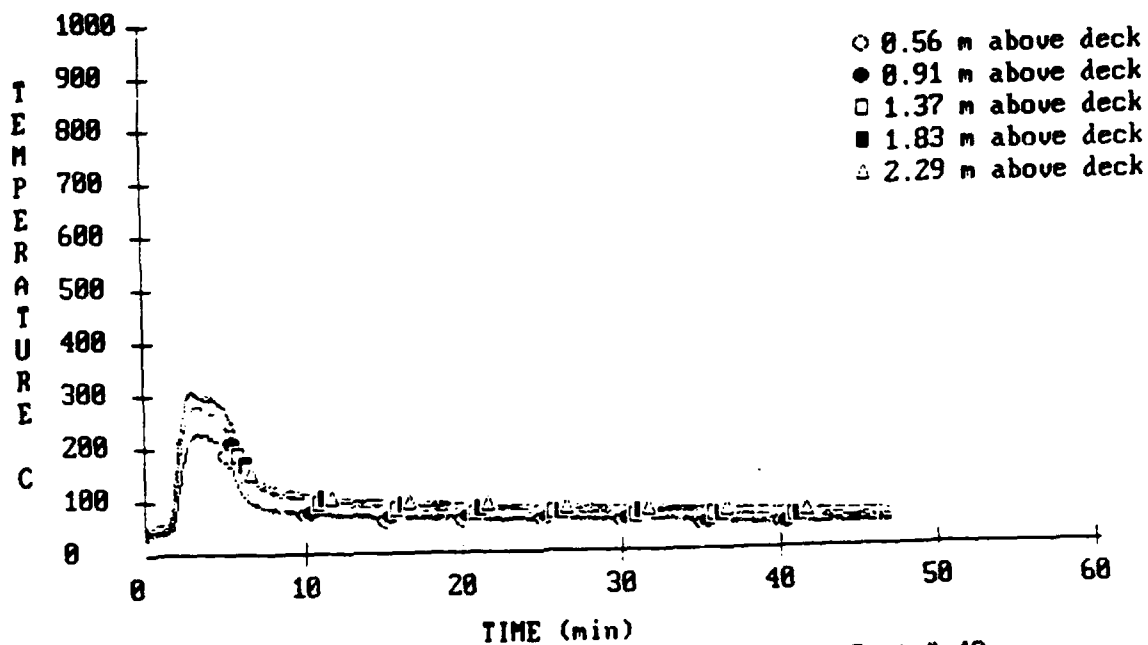


Fig. B-390- Temperature in BERTHING 2 (3-83-6) during Test # 40

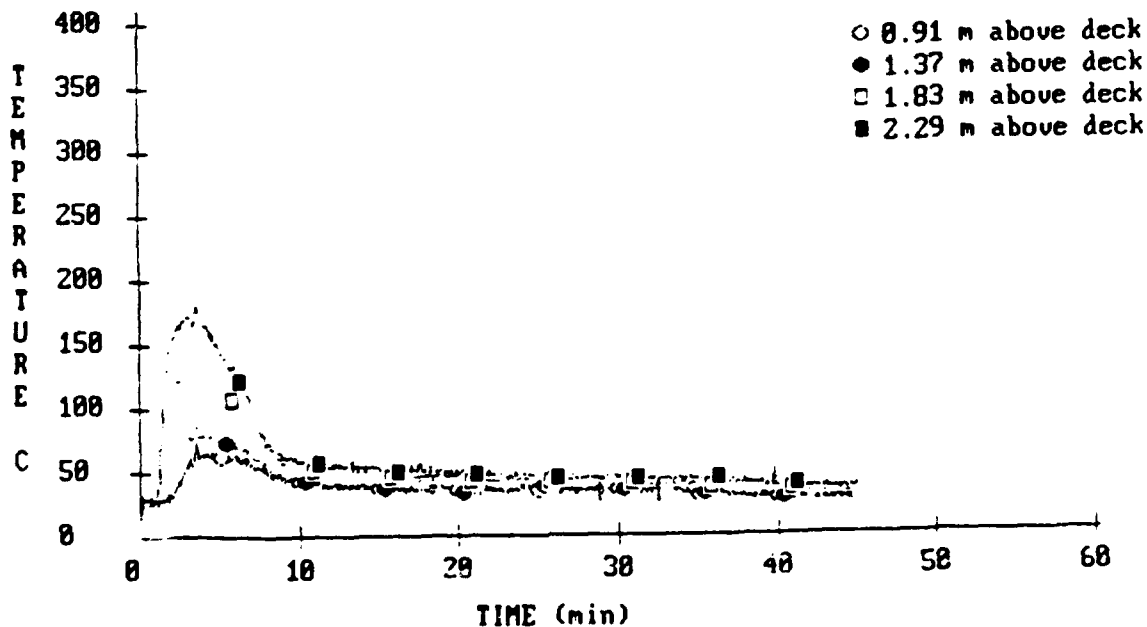


Fig. B-391- Temperature in BERTHING 1 (3-79-2) during Test # 2

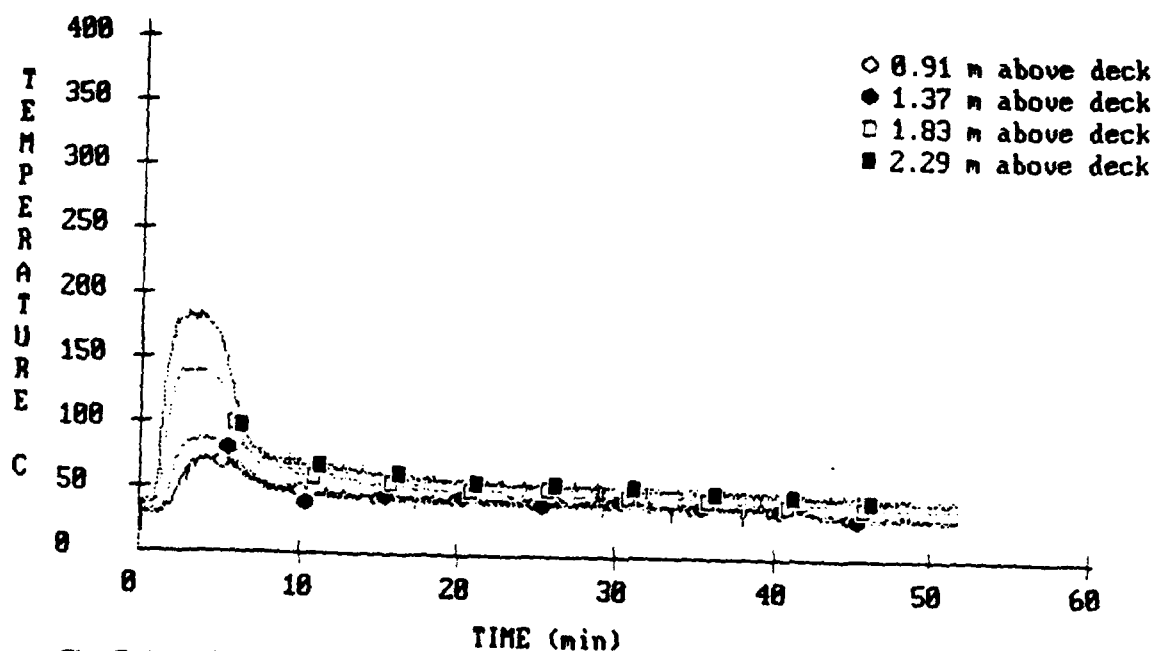


Fig. B-392- Temperature in BERTHING 1 (3-79-2) during Test # 3

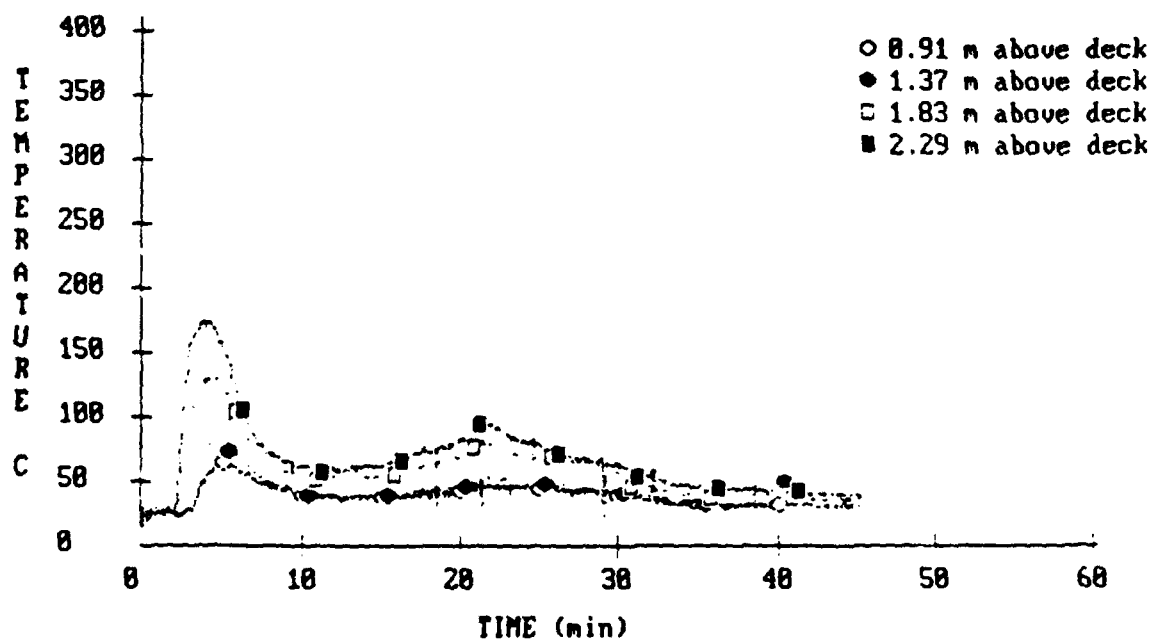


Fig. B-393- Temperature in BERTHING 1 (3-79-2) during Test # 4

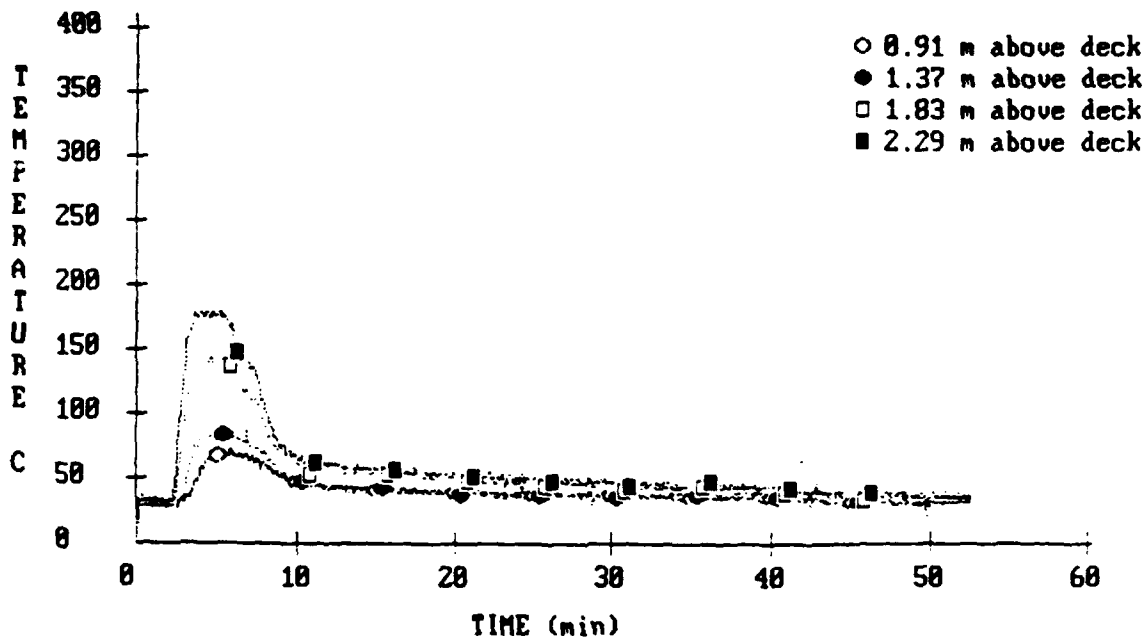


Fig. B-394- Temperature in BERTHING 1 (3-79-2) during Test # 5

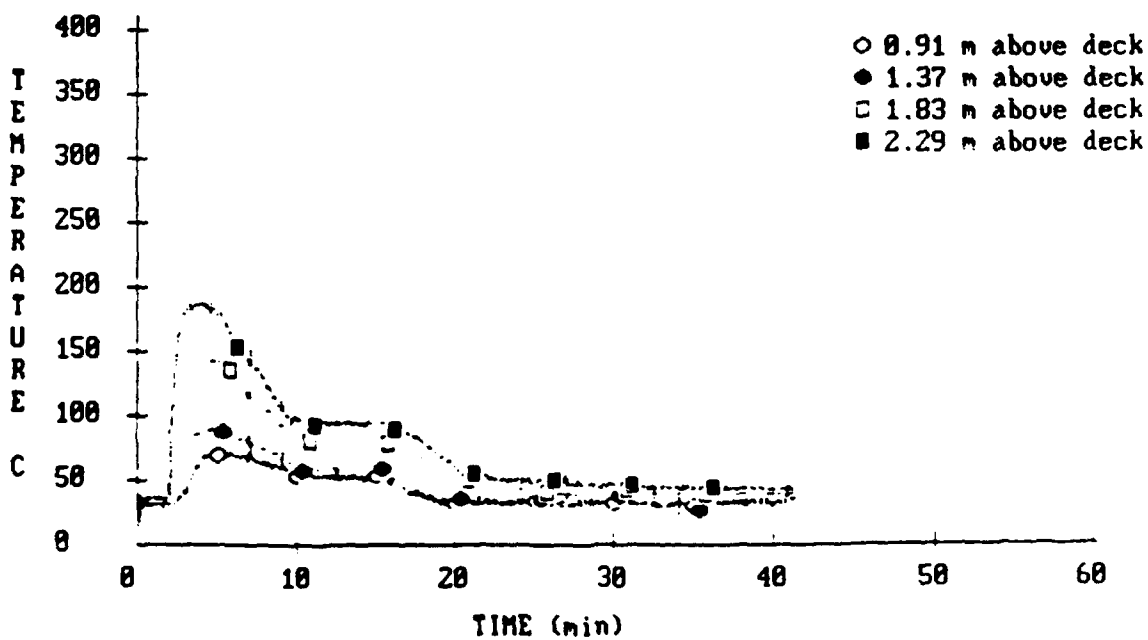


Fig. B-395- Temperature in BERTHING 1 (3-79-2) during Test # 6

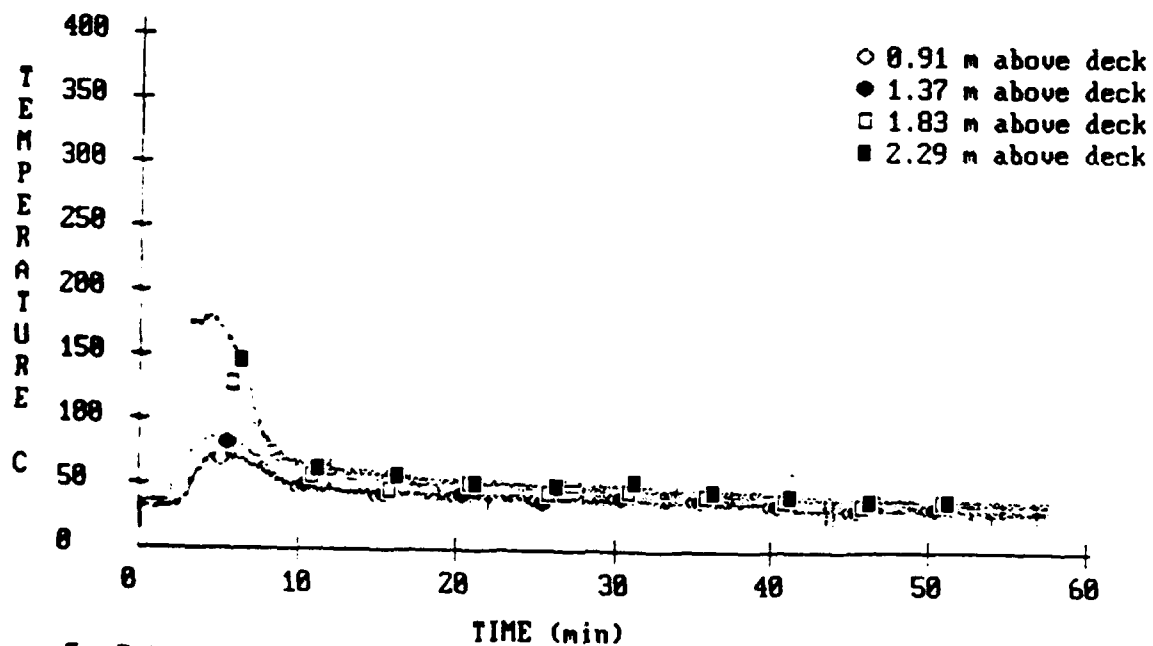


Fig. B-396- Temperature in BERTHING 1 (3-79-2) during Test # 7

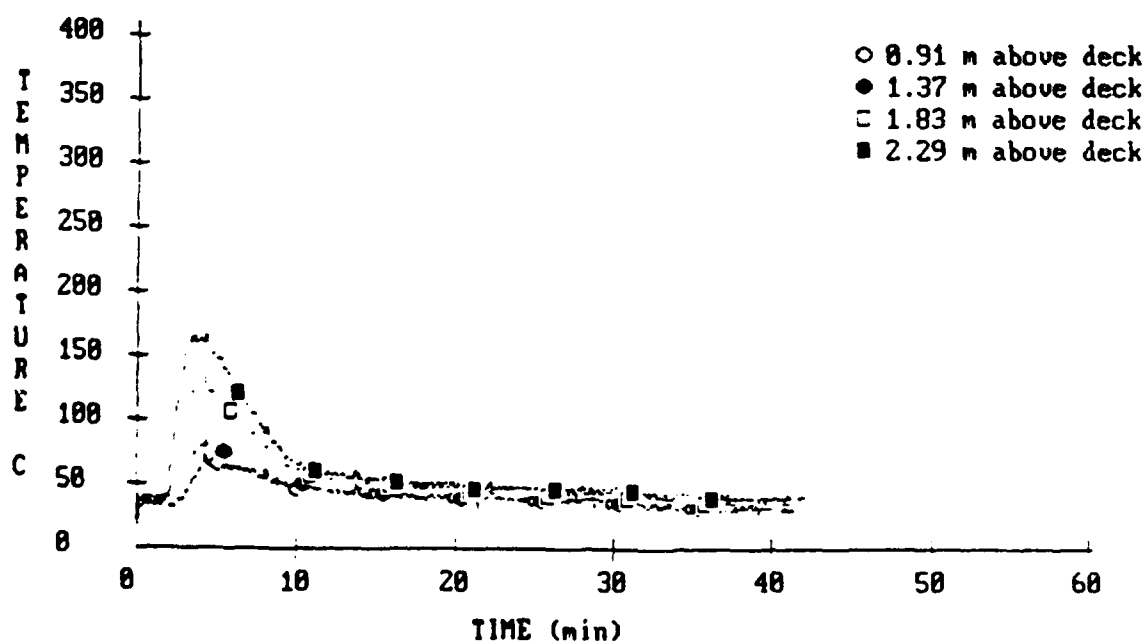


Fig. B-397- Temperature in BERTHING 1 (3-79-2) during Test # 8

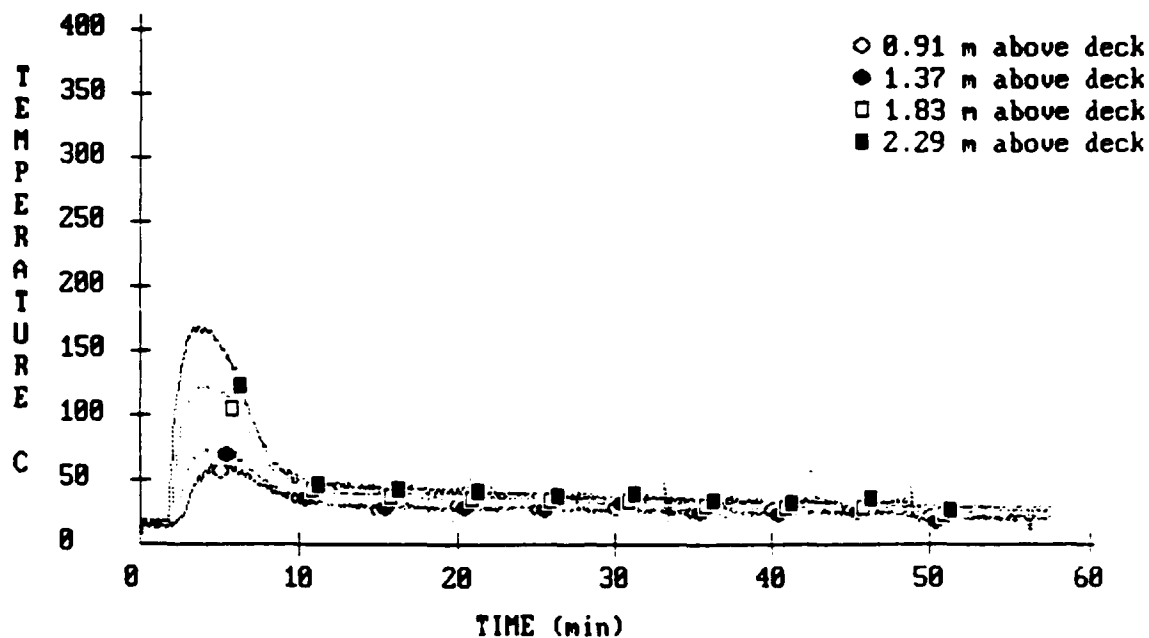


Fig. B-398- Temperature in BERTHING 1 (3-79-2) during Test # 9

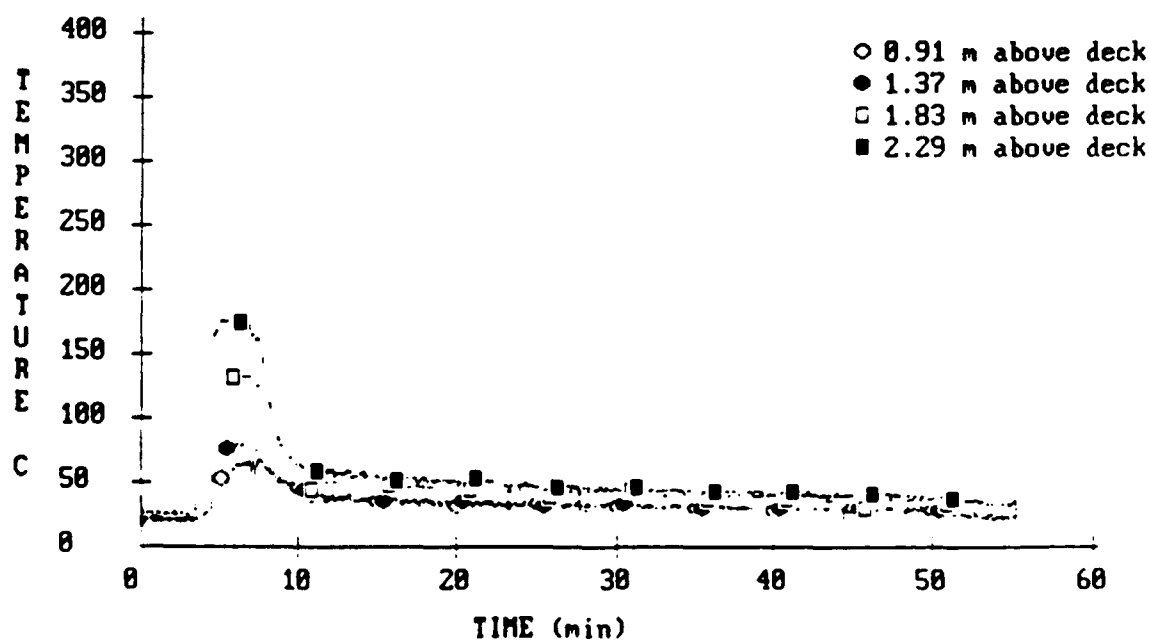


Fig. B-399- Temperature in BERTHING 1 (3-79-2) during Test # 10

B-204

Fig. B-403- Temperature in BERTHING 1 (3-79-2) during Test # 14

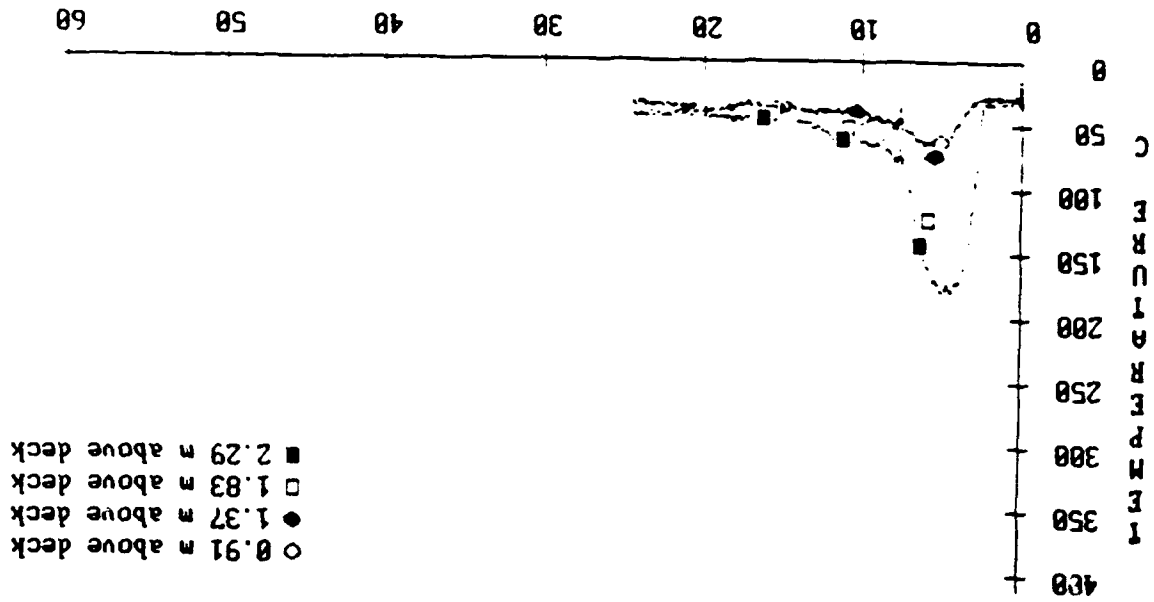


Fig. B-402- Temperature in BERTHING 1 (3-79-2) during Test # 13

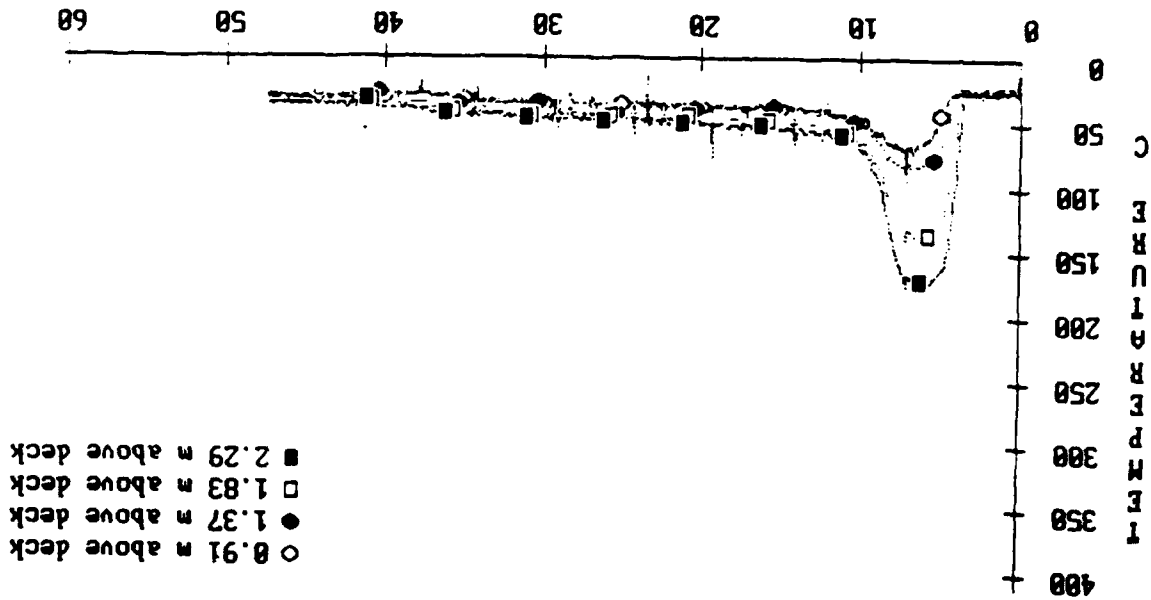


Fig. B-401- Temperature in BERTHING 1 (3-79-2) during Test # 12

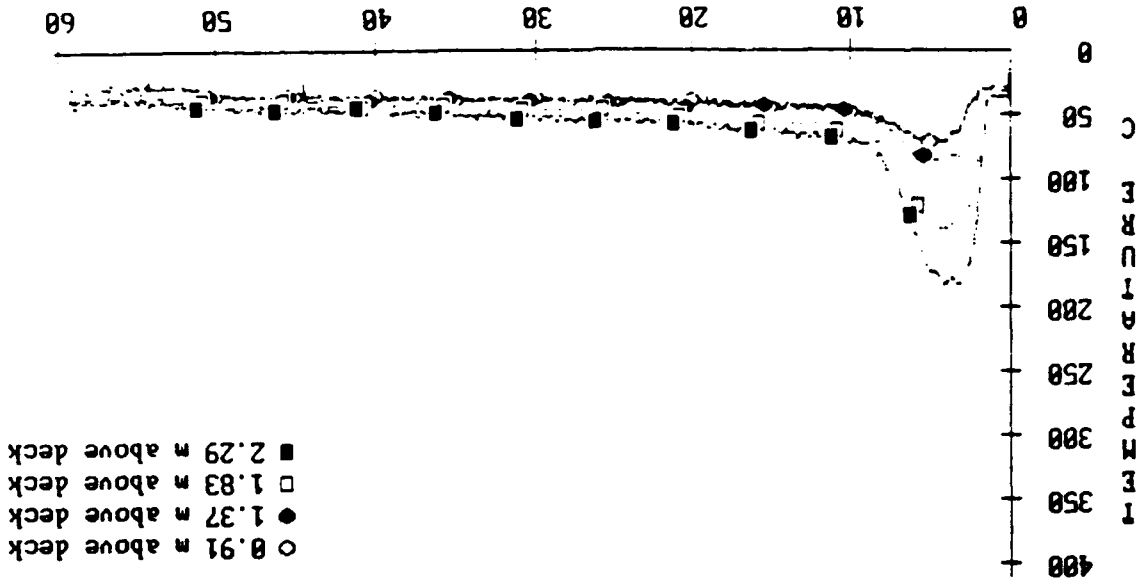
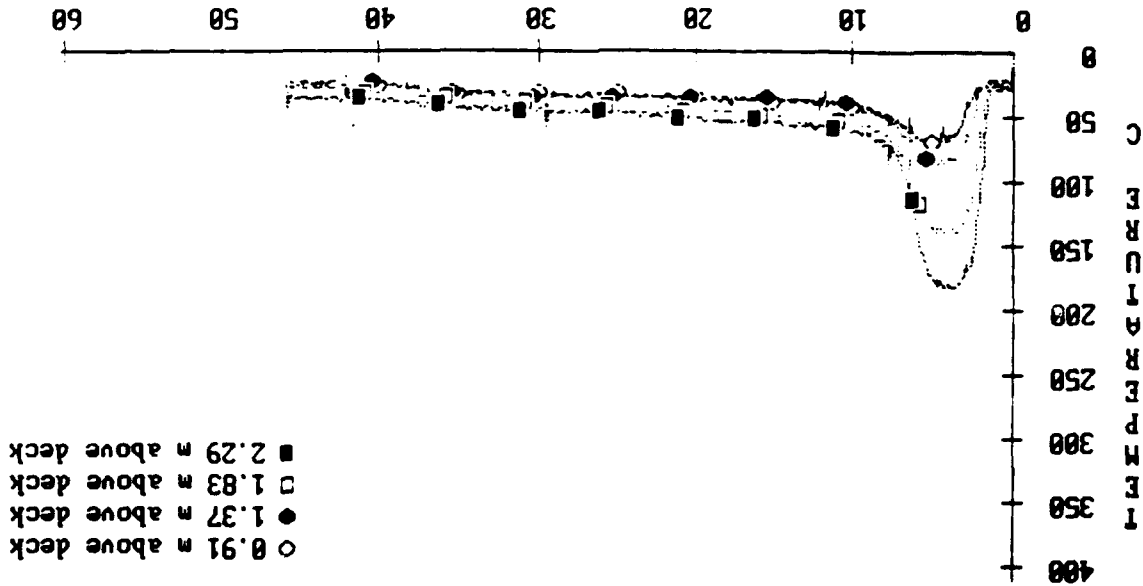


Fig. B-400- Temperature in BERTHING 1 (3-79-2) during Test # 11



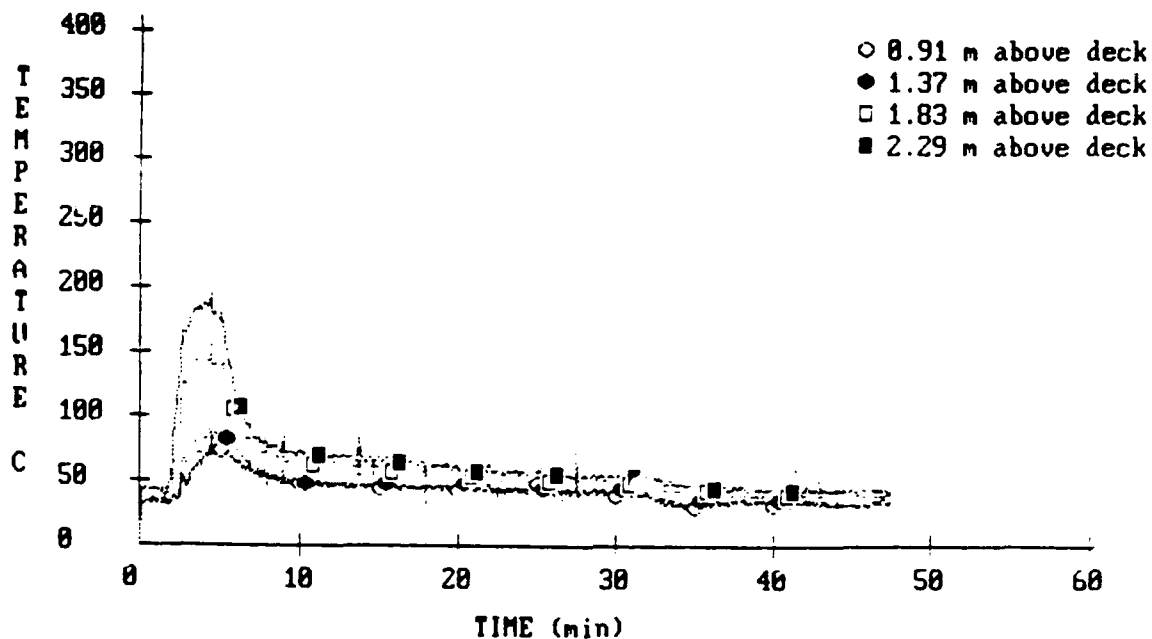


Fig. B-404- Temperature in BERTHING 1 (3-79-2) during Test # 15

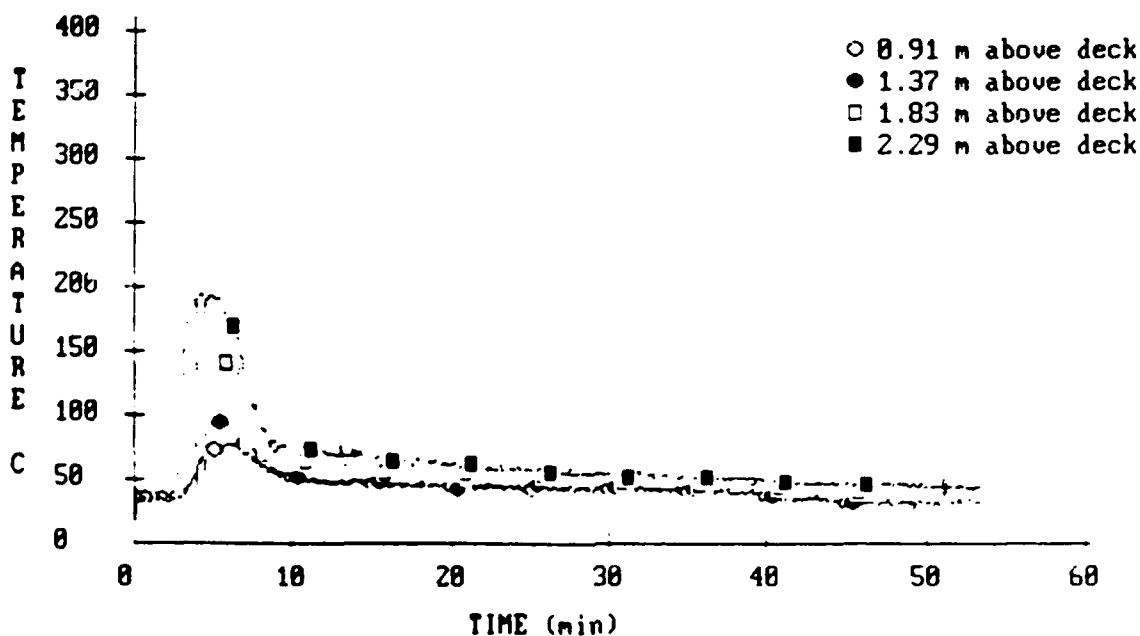


Fig. B-405- Temperature in BERTHING 1 (3-79-2) during Test # 16



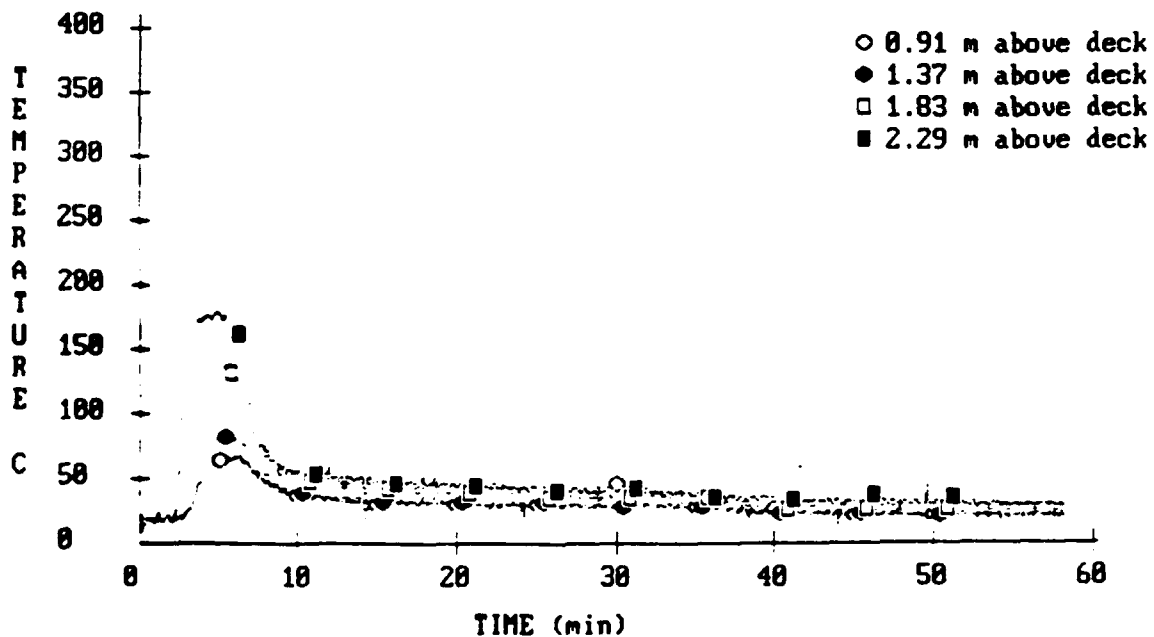


Fig. B-406- Temperature in BERTHING 1 (3-79-2) during Test # 17

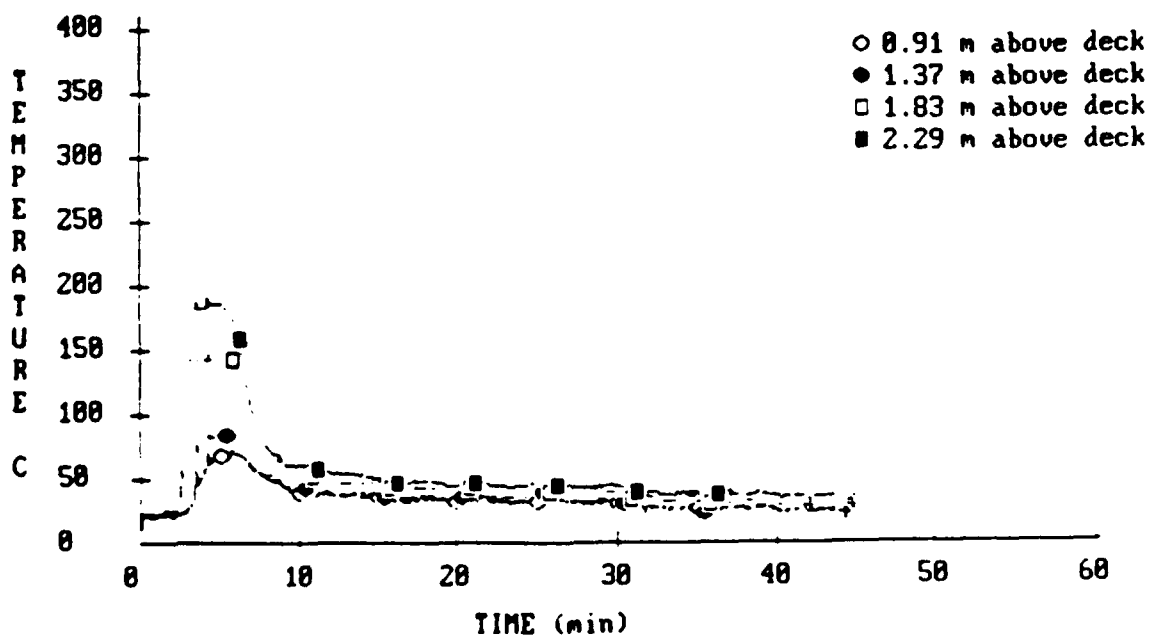


Fig. B-407- Temperature in BERTHING 1 (3-79-2) during Test # 18

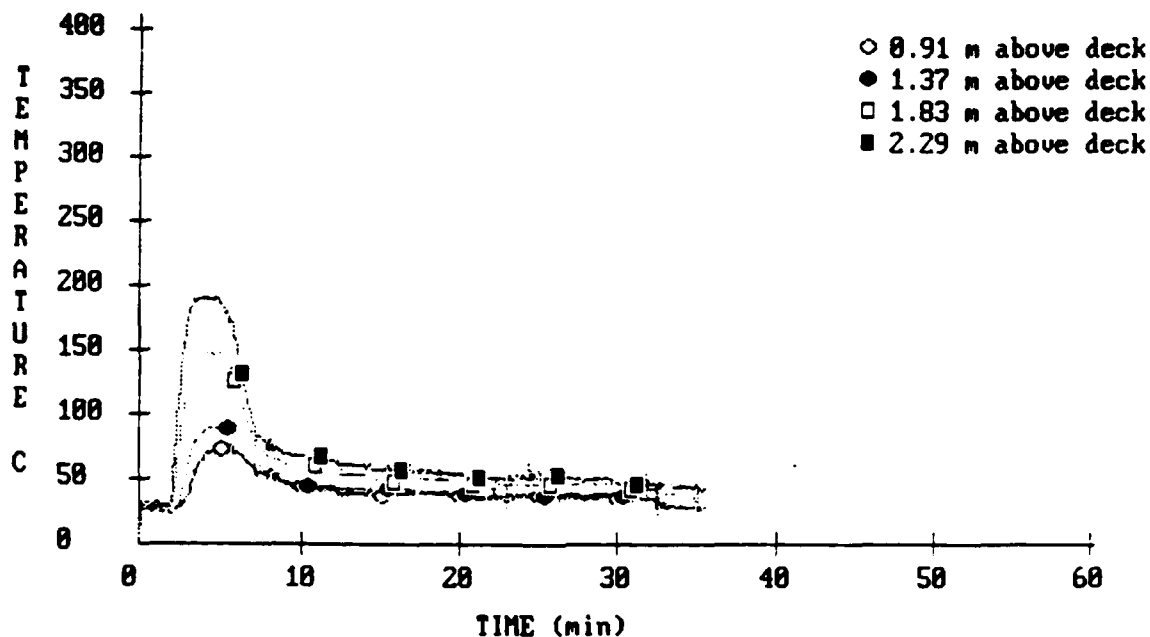


Fig. B-408- Temperature in BERTHING 1 (3-79-2) during Test # 19

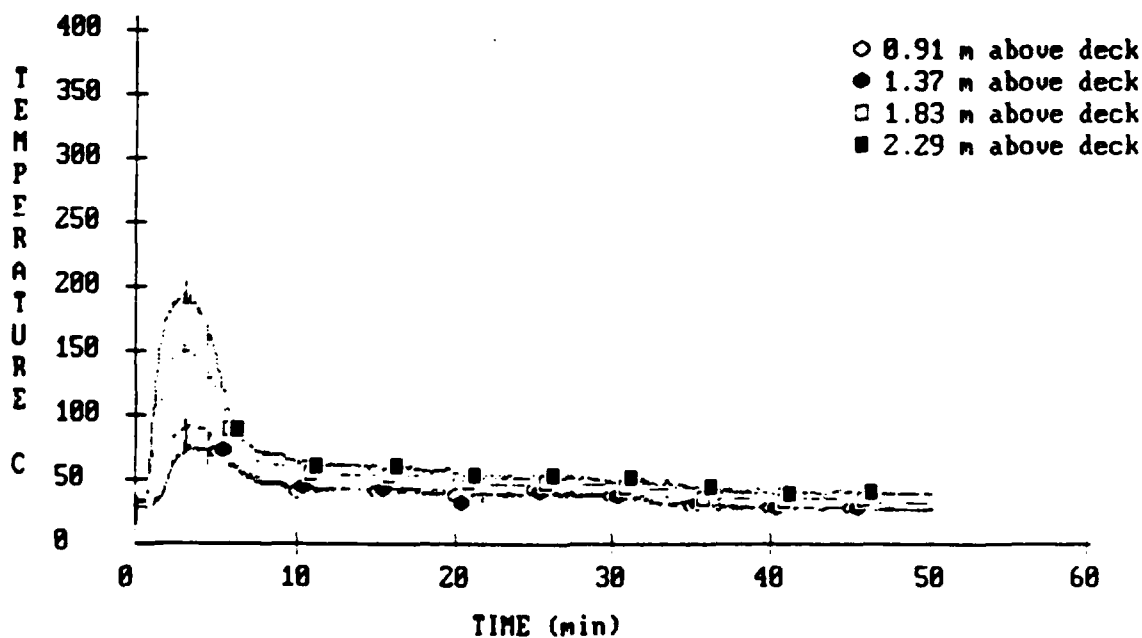


Fig. B-409- Temperature in BERTHING 1 (3-79-2) during Test # 28

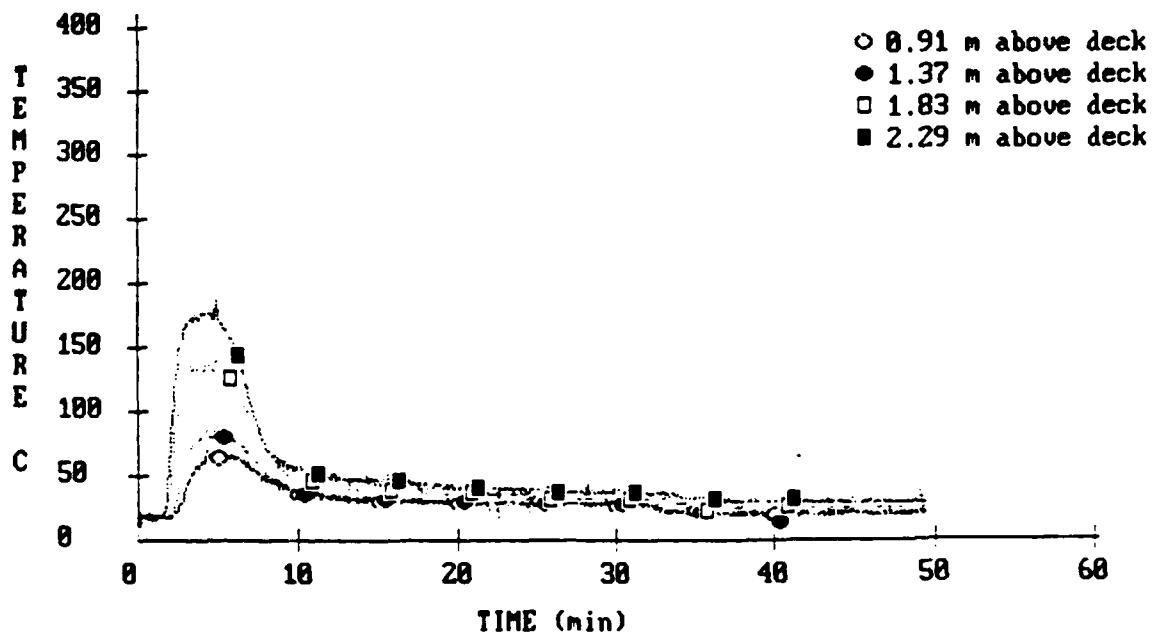


Fig. B-410- Temperature in BERTHING 1 (3-79-2) during Test # 21

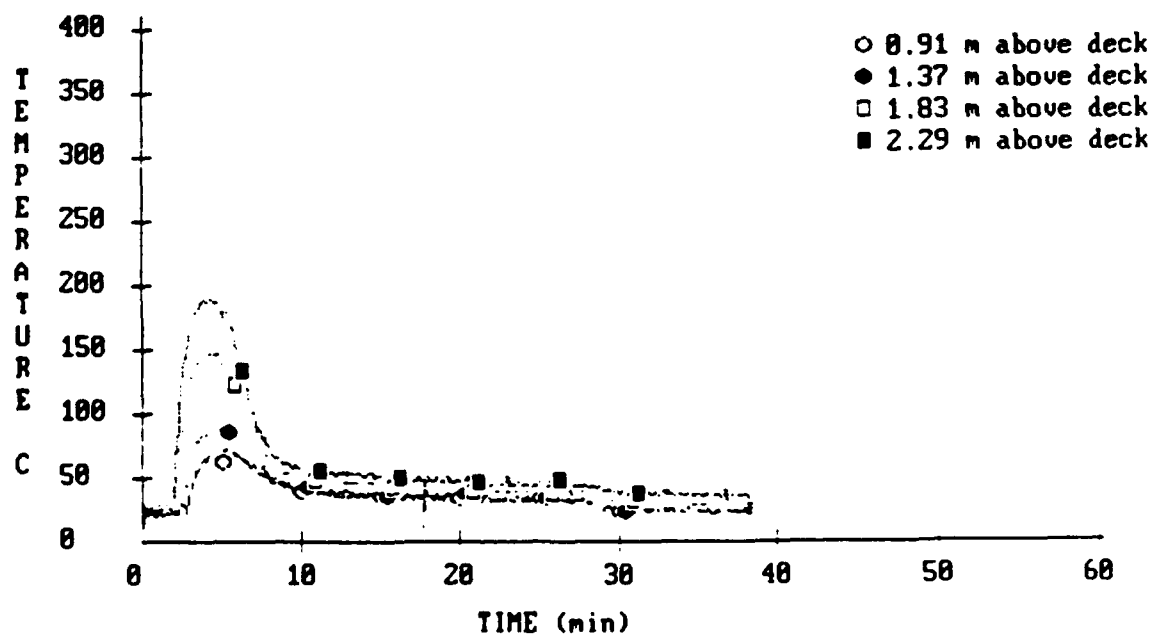


Fig. B-411- Temperature in BERTHING 1 (3-79-2) during Test # 22

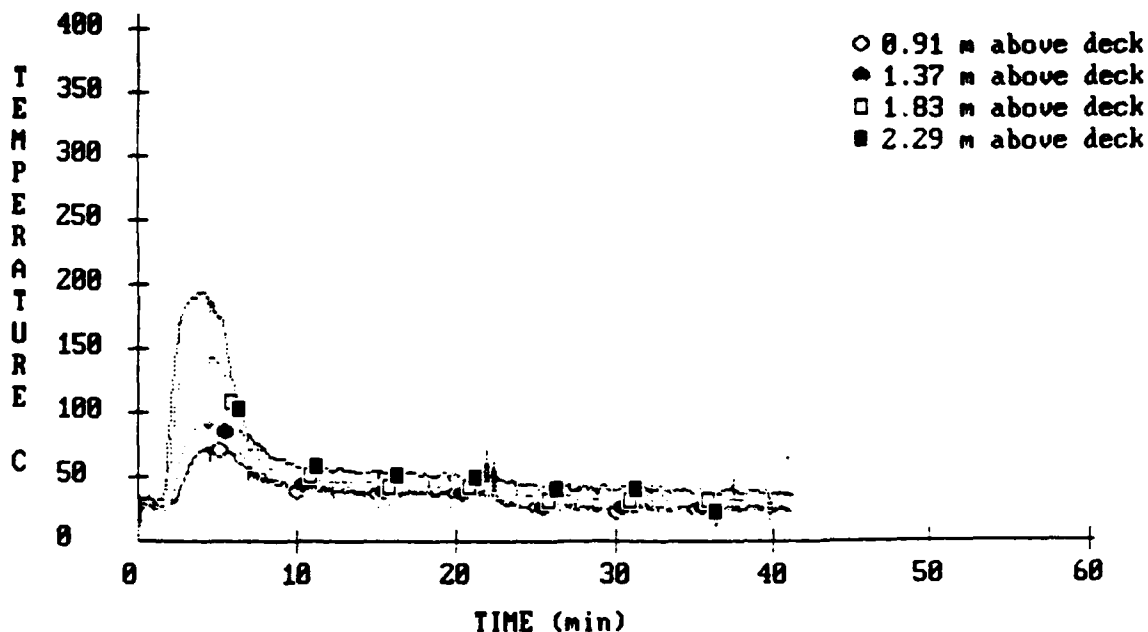


Fig. B-412- Temperature in BERTHING 1 (3-79-2) during Test # 23

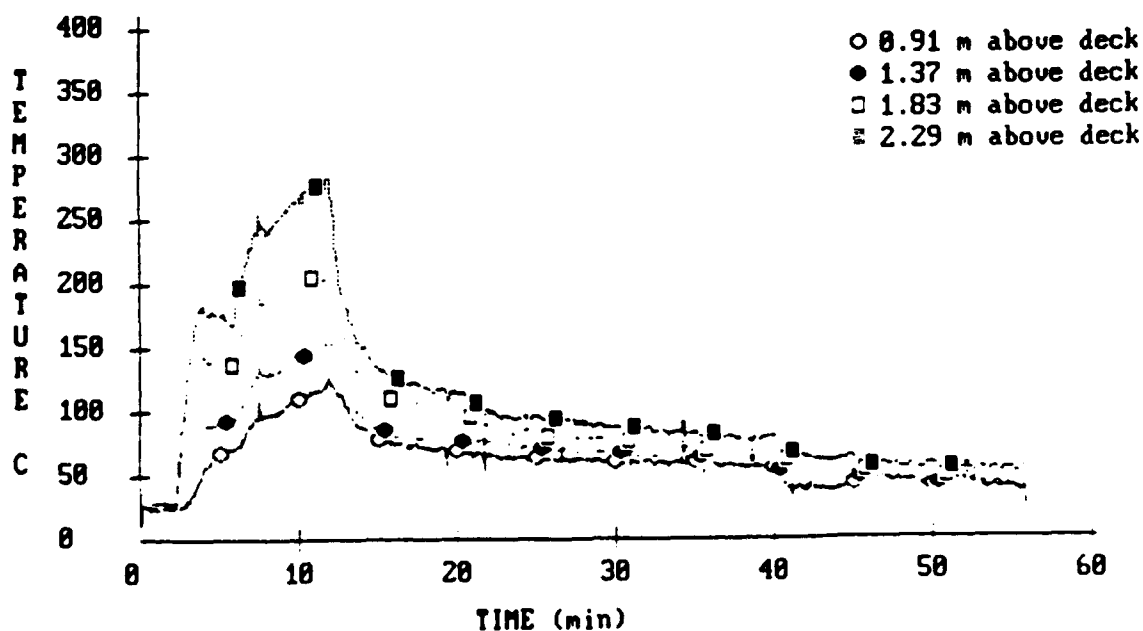


Fig. B-413- Temperature in BERTHING 1 (3-79-2) during Test # 24

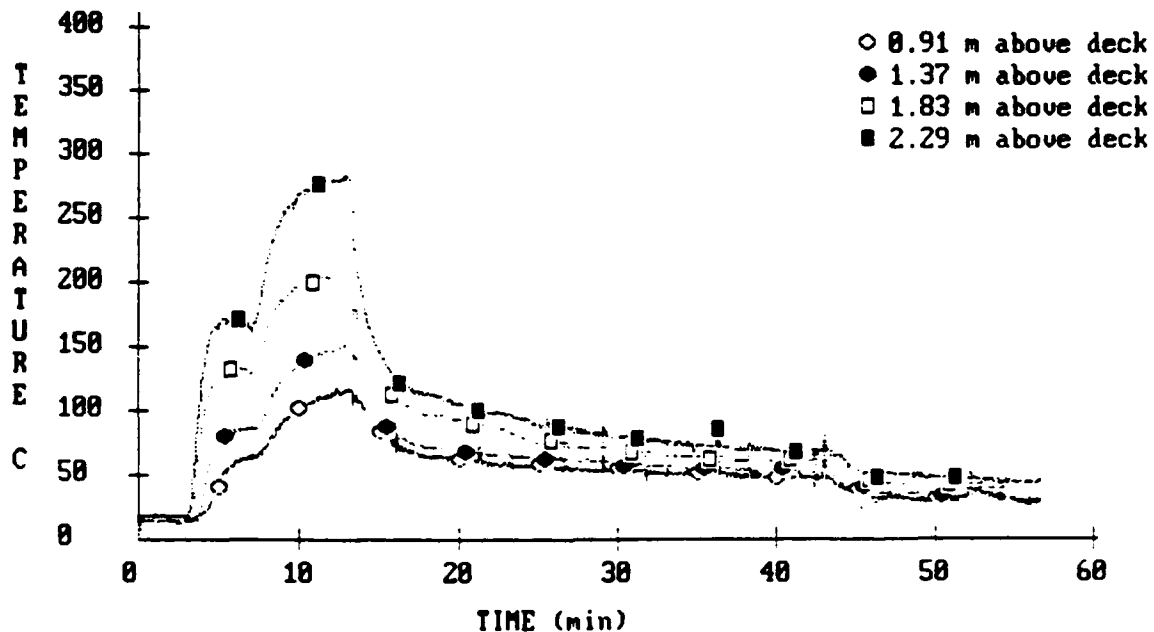


Fig. B-414- Temperature in BERTHING 1 (3-79-2) during Test # 25

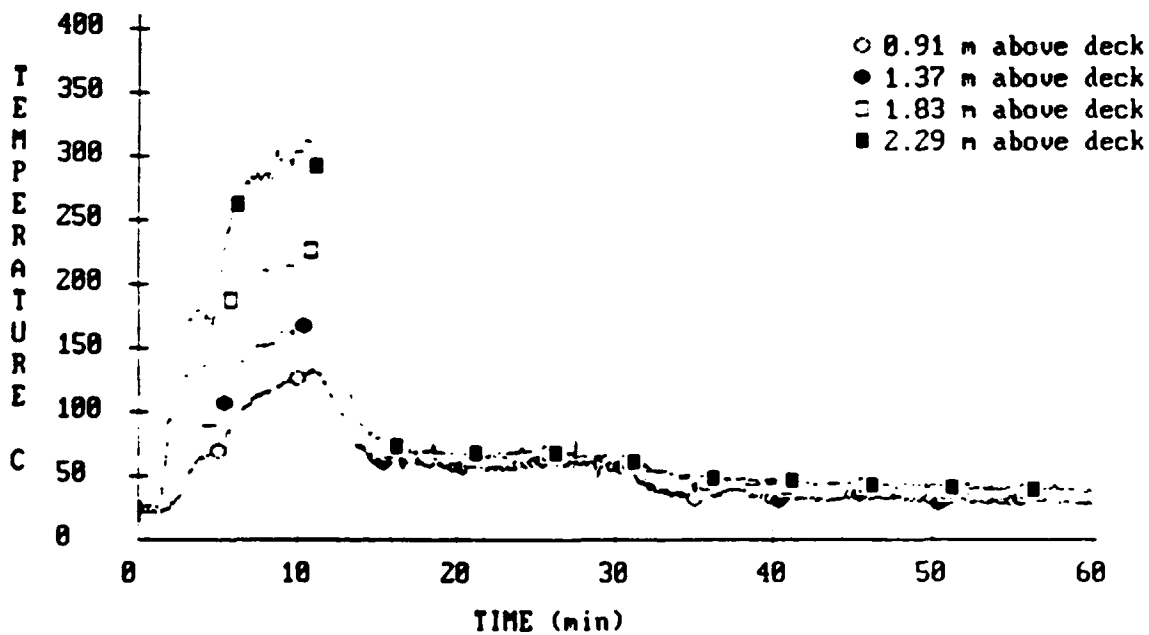


Fig. B-415- Temperature in BERTHING 1 (3-79-2) during Test # 26

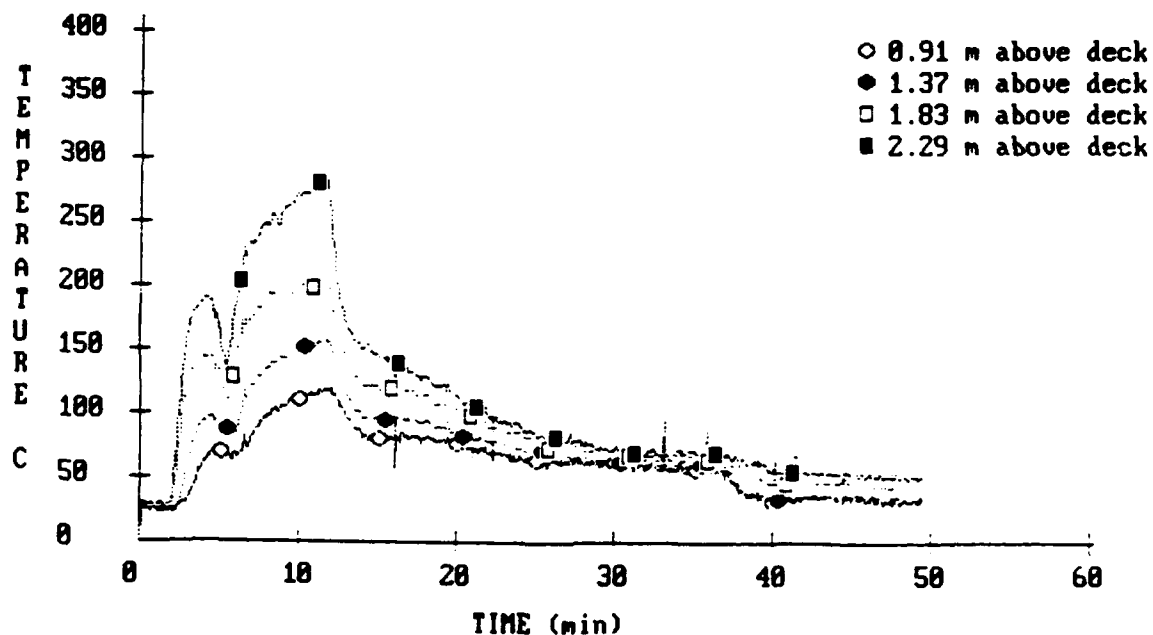


Fig. B-416- Temperature in BERTHING 1 (3-79-2) during Test # 27

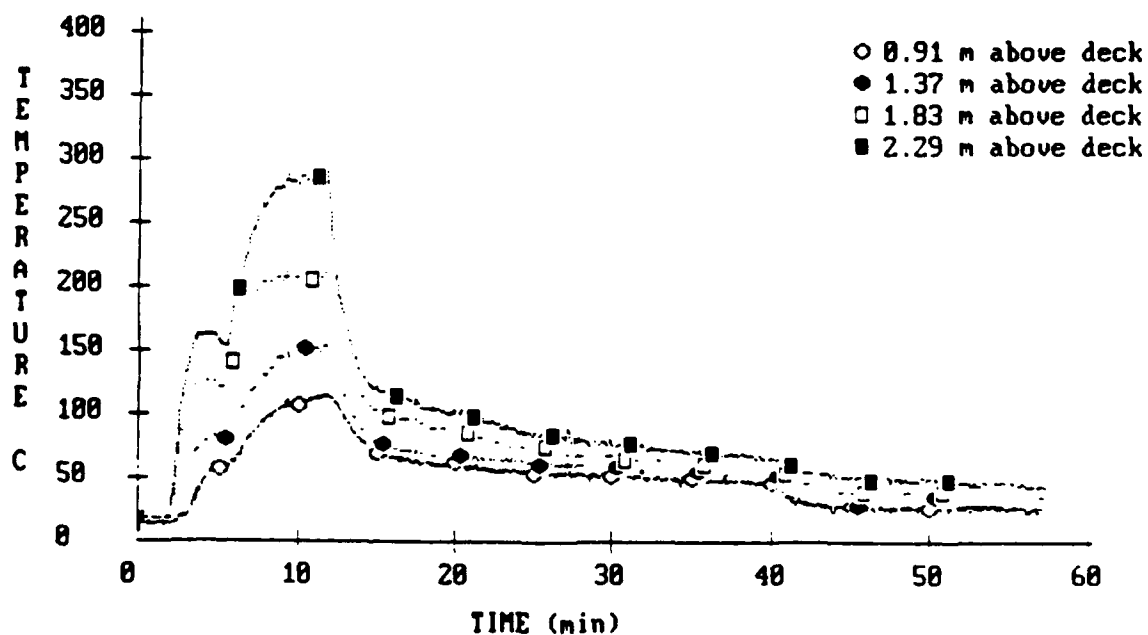


Fig. B-417- Temperature in BERTHING 1 (3-79-2) during Test # 28

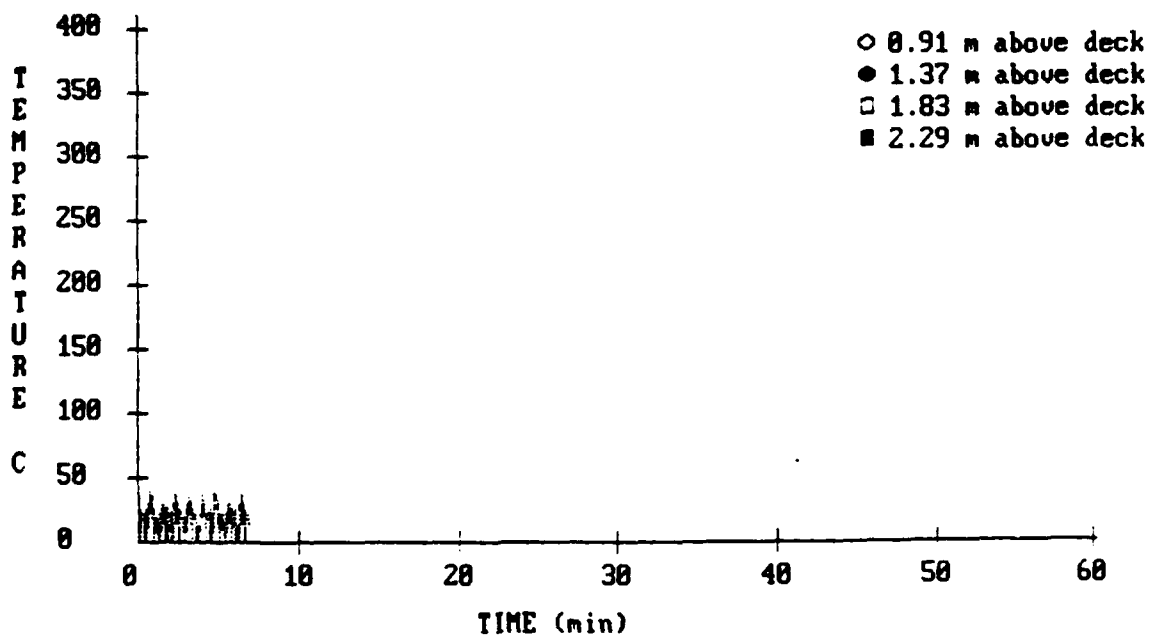


Fig. B-418- Temperature in BERTHING 1 (3-79-2) during Test # 29

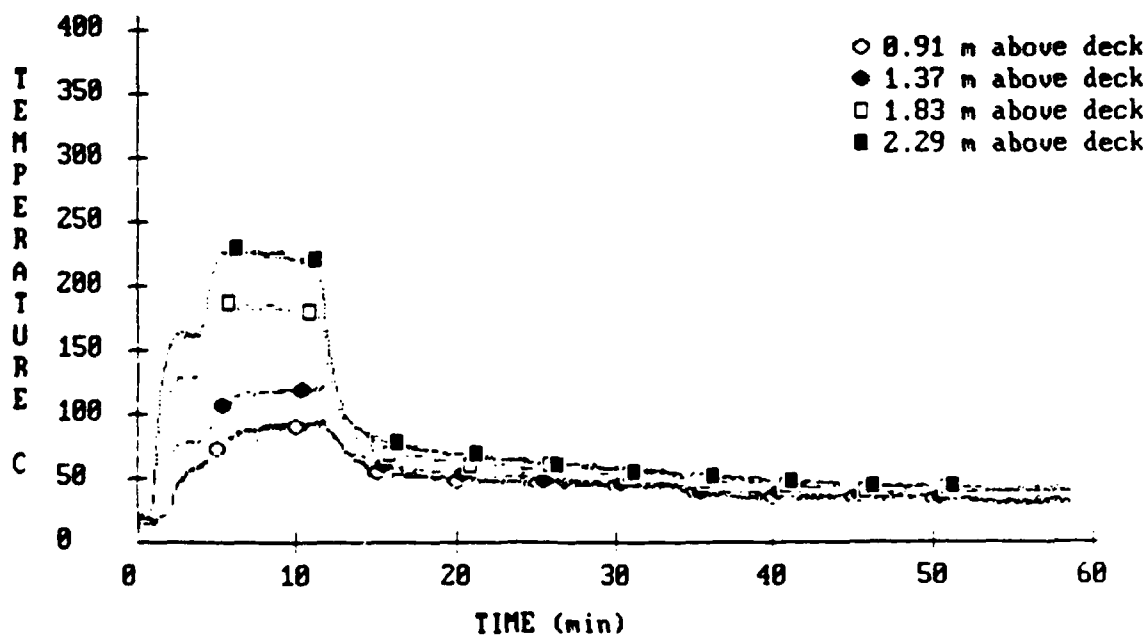


Fig. B-419- Temperature in BERTHING 1 (3-79-2) during Test # 30

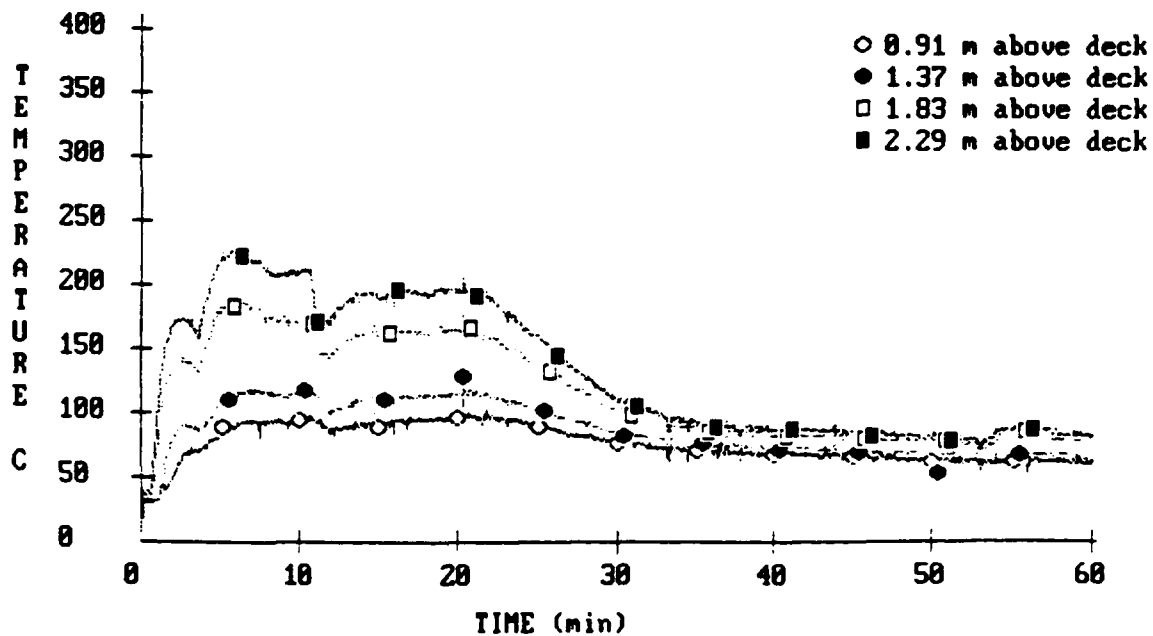


Fig. B-420- Temperature in BERTHING 1 (3-79-2) during Test # 31

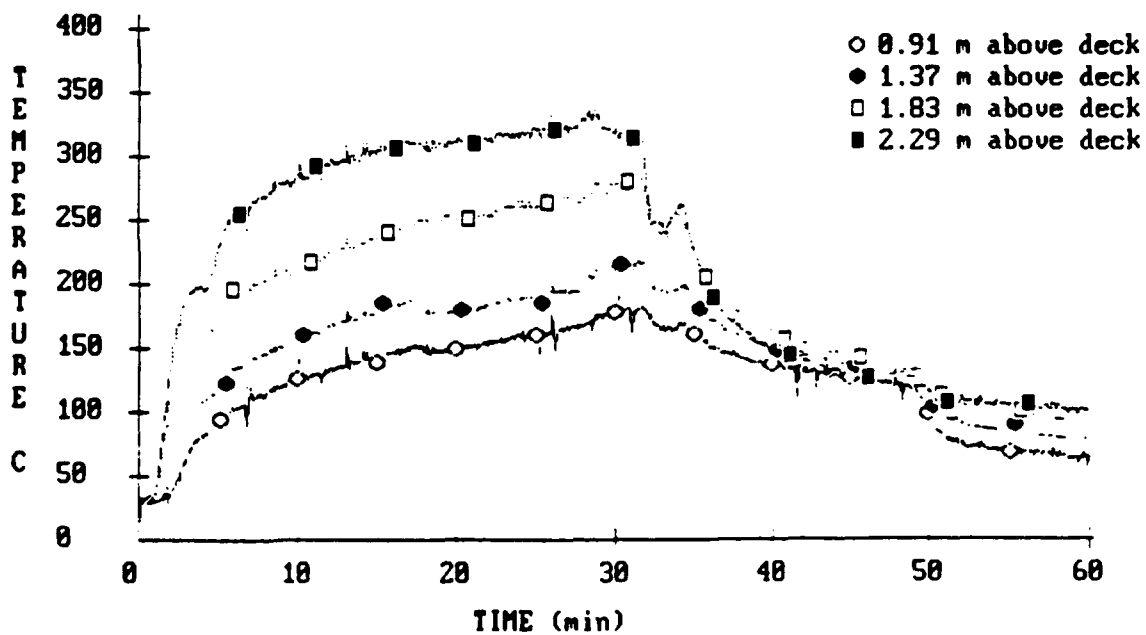


Fig. B-421- Temperature in BERTHING 1 (3-79-2) during Test # 32



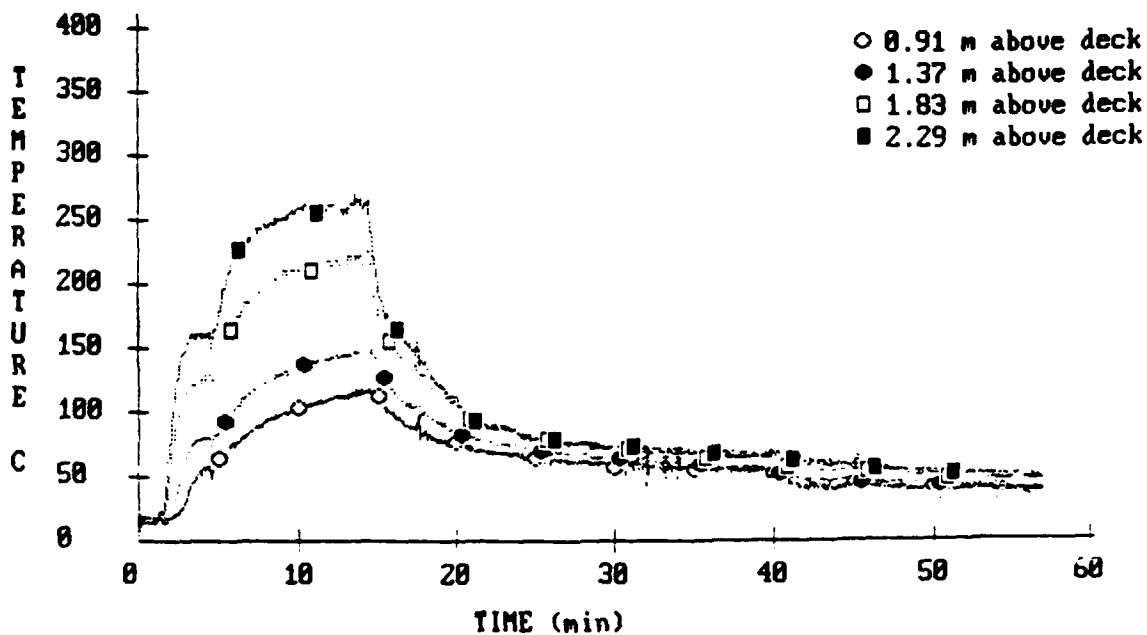


Fig. B-422- Temperature in BERTHING 1 (3-79-2) during Test # 33

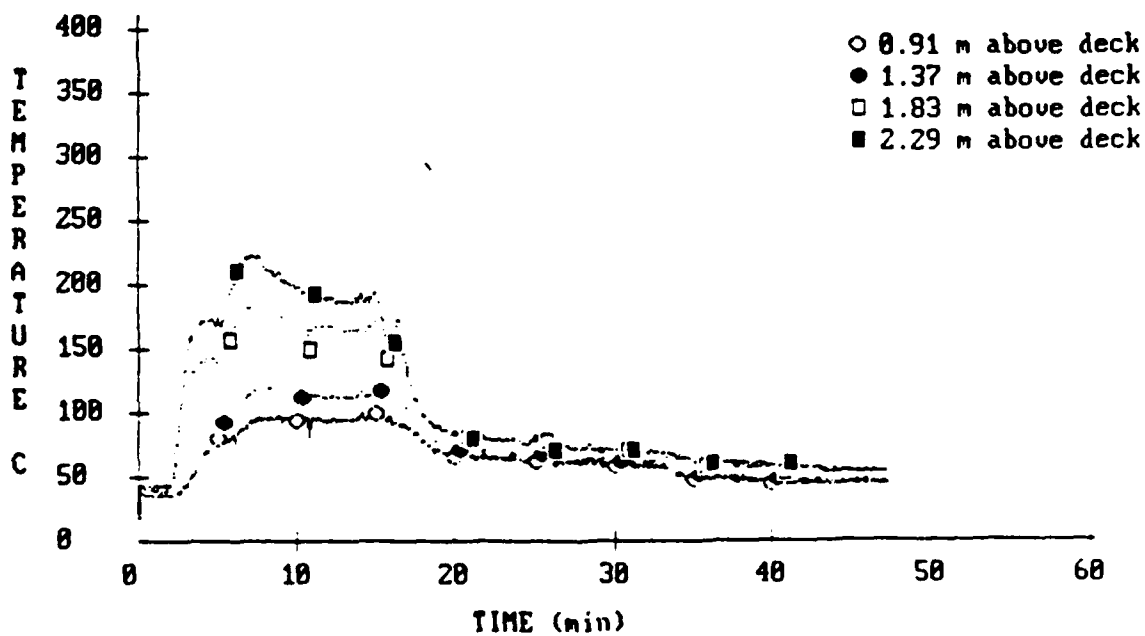


Fig. B-423- Temperature in BERTHING 1 (3-79-2) during Test # 34

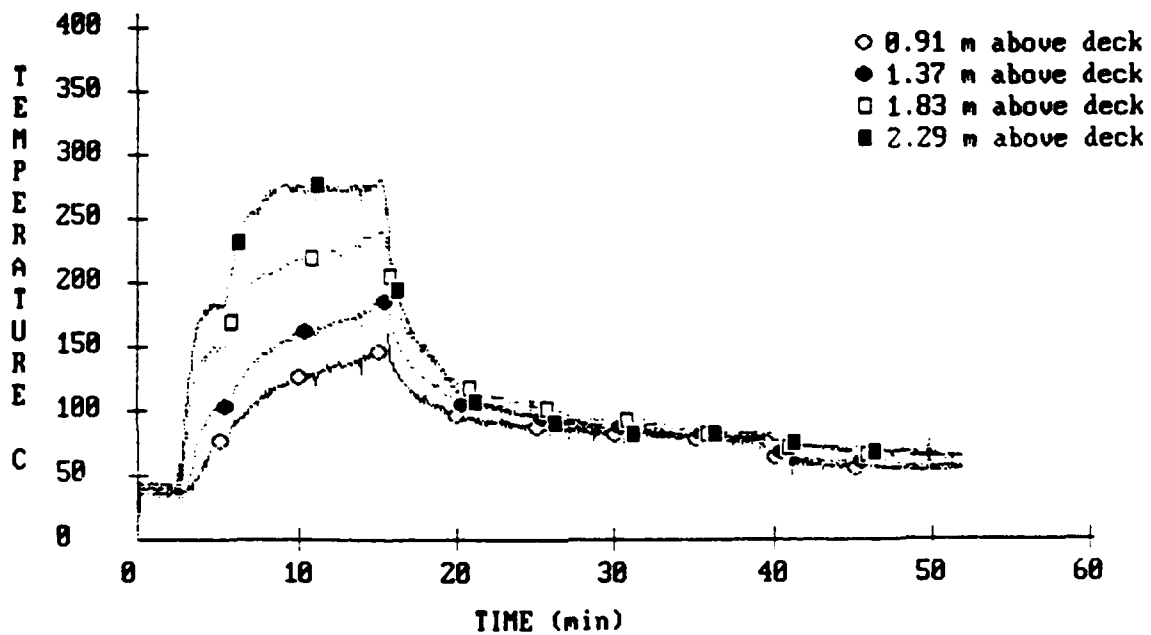


Fig. B-424- Temperature in BERTHING 1 (3-79-2) during Test # 35

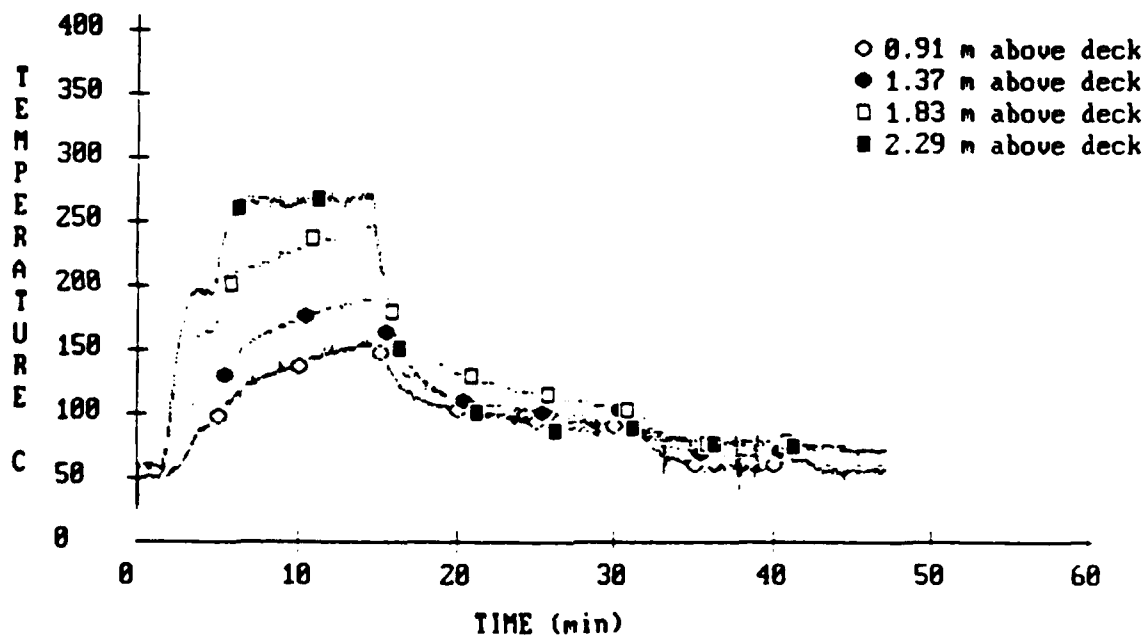


Fig. B-425- Temperature in BERTHING 1 (3-79-2) during Test # 36

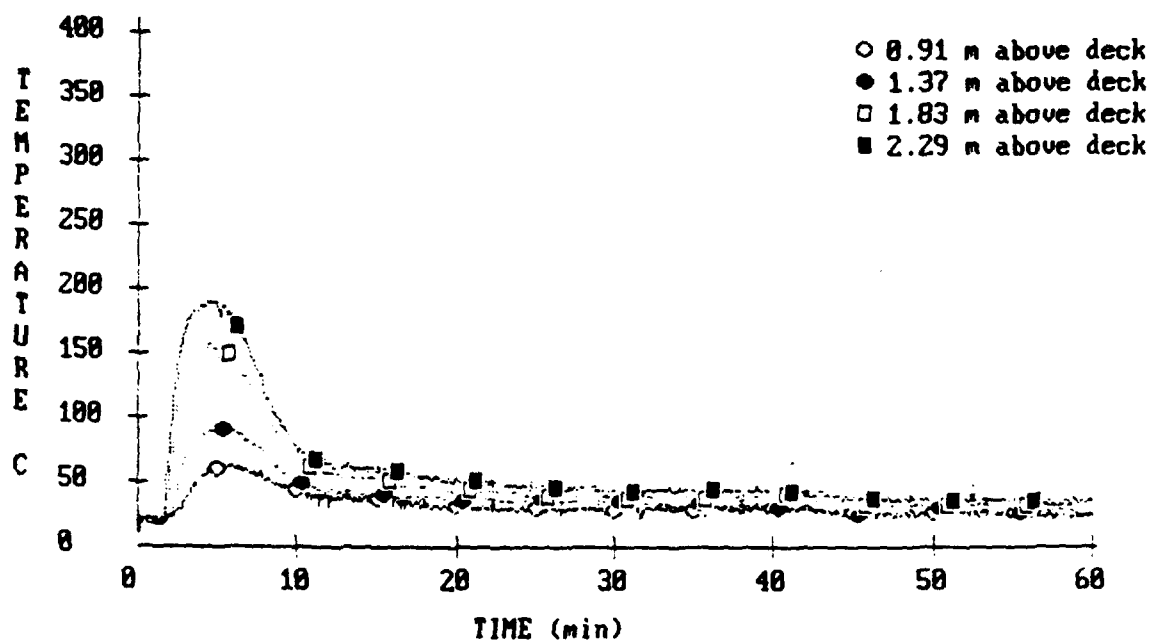


Fig. B-426- Temperature in BERTHING 1 (3-79-2) during Test # 37

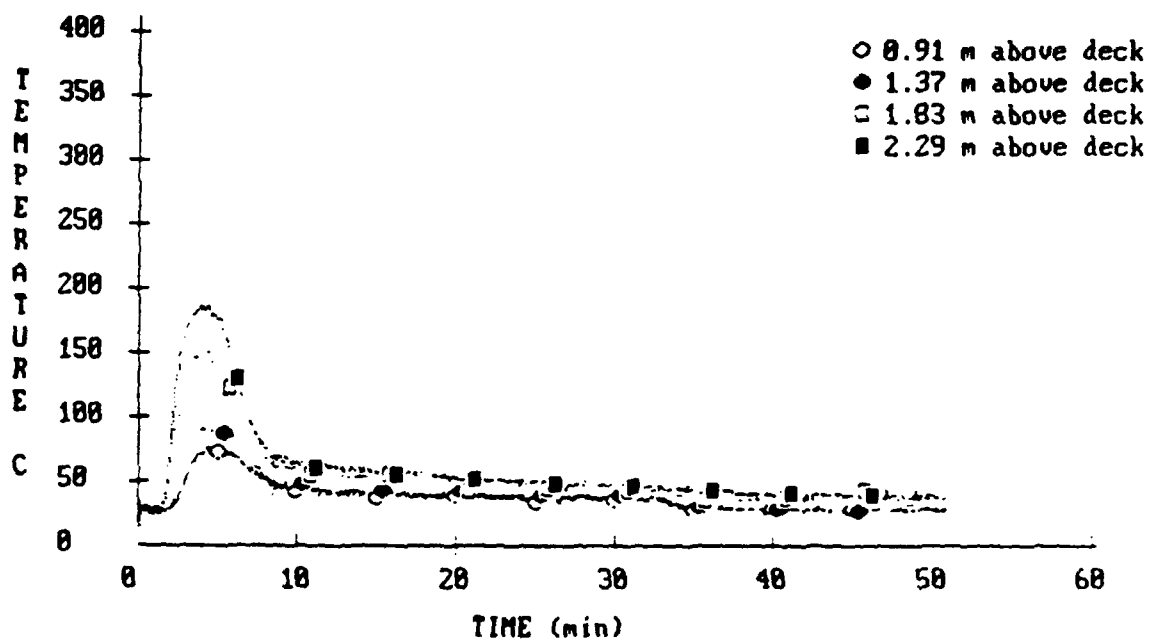


Fig. B-427- Temperature in BERTHING 1 (3-79-2) during Test # 38

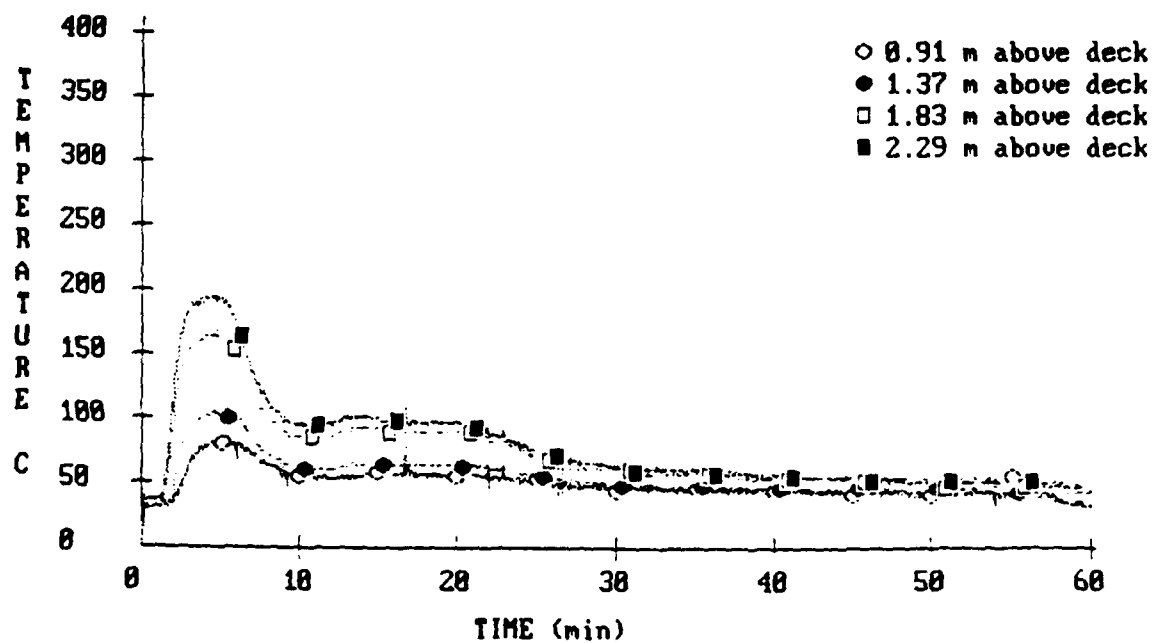


Fig. B-428- Temperature in BERTHING 1 (3-79-2) during Test # 39

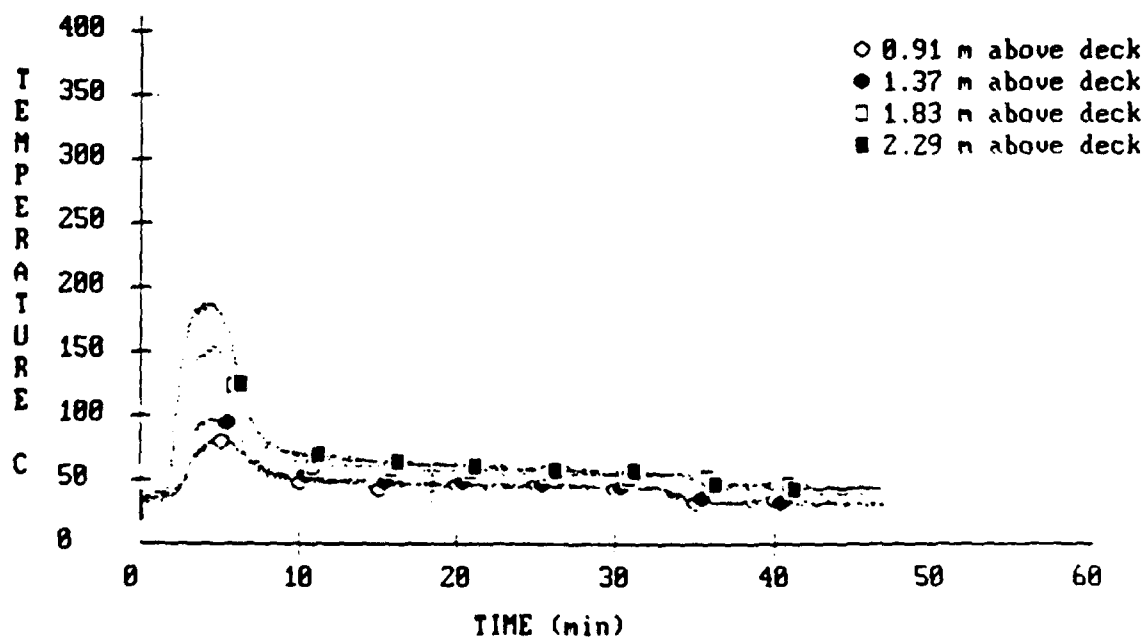


Fig. B-429- Temperature in BERTHING 1 (3-79-2) during Test # 40

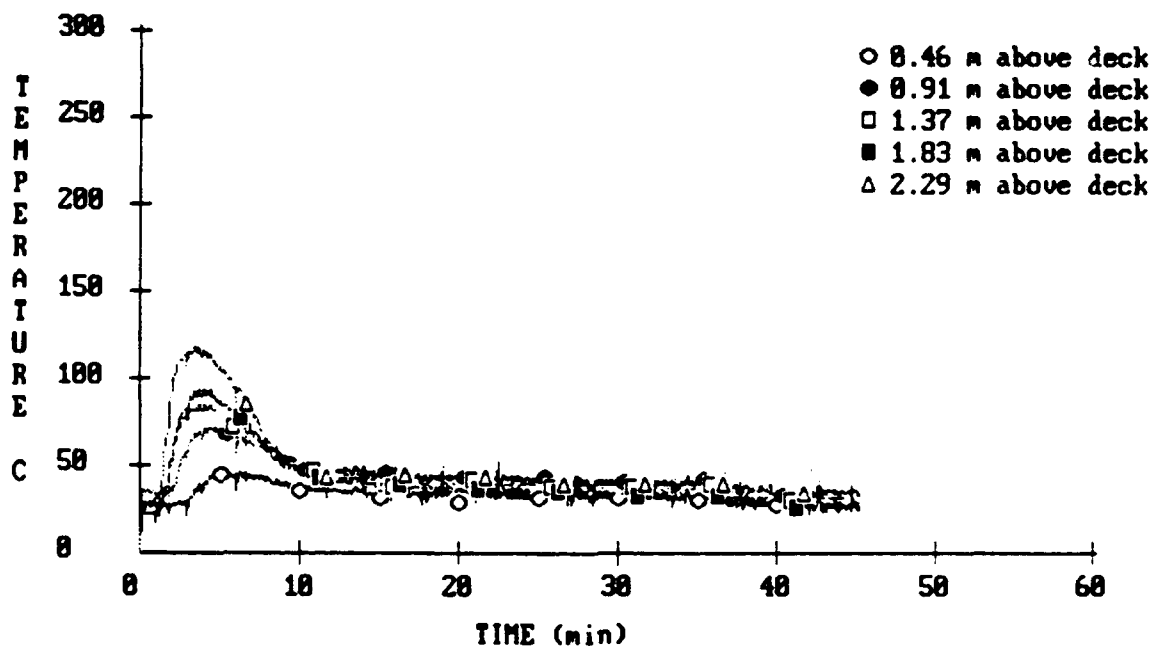


Fig. B-430- Temperature in BERTHING 1 (3-76-2) during Test # 2

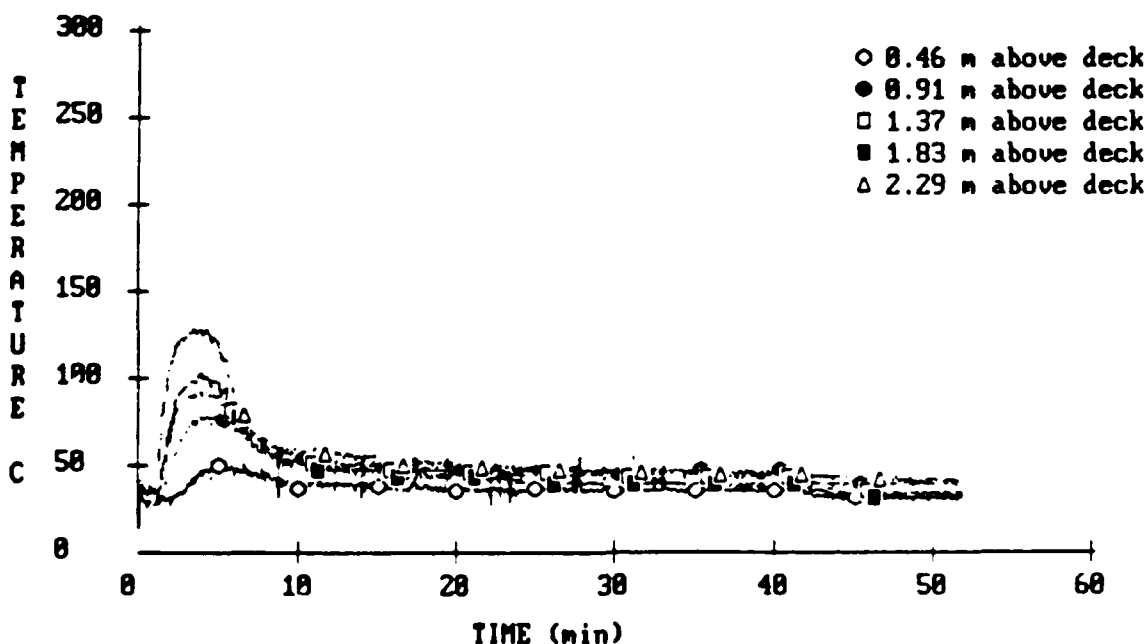


Fig. B-431- Temperature in BERTHING 1 (3-76-2) during Test # 3

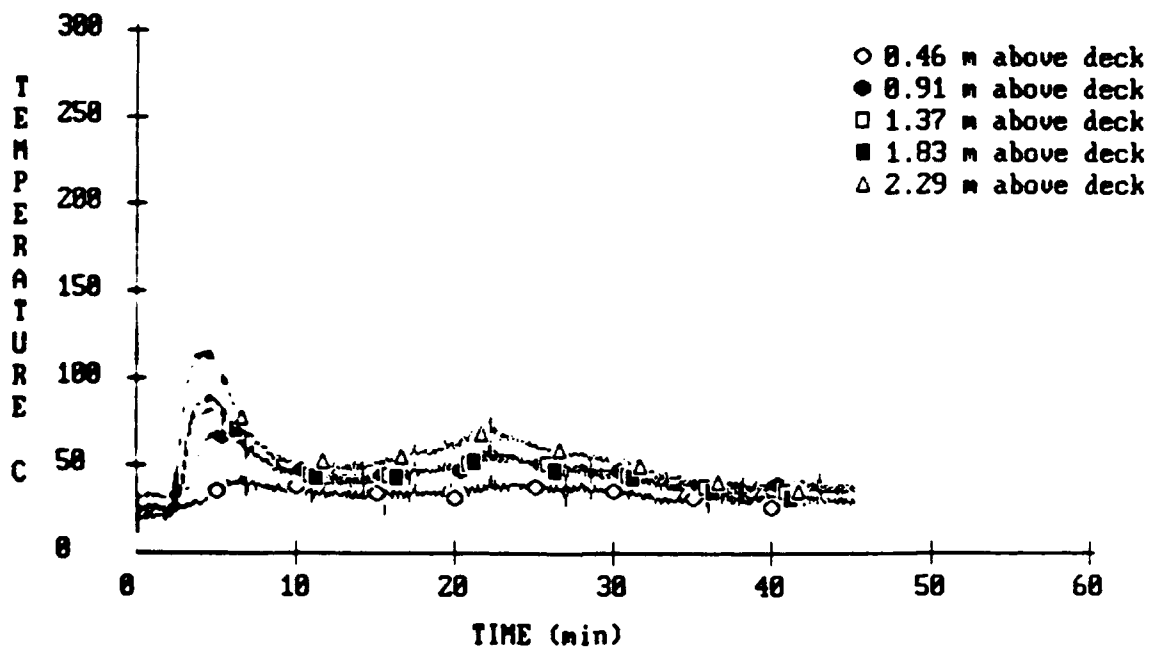


Fig. B-432- Temperature in BERTHING 1 (3-76-2) during Test # 4

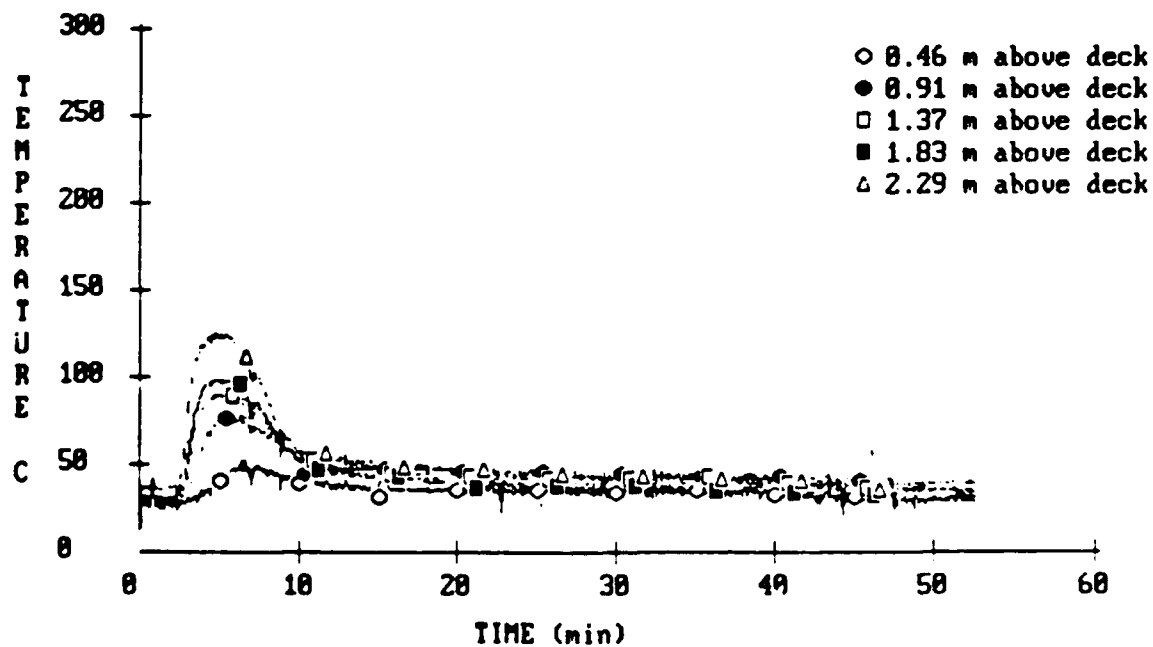


Fig. B-433- Temperature in BERTHING 1 (3-76-2) during Test # 5

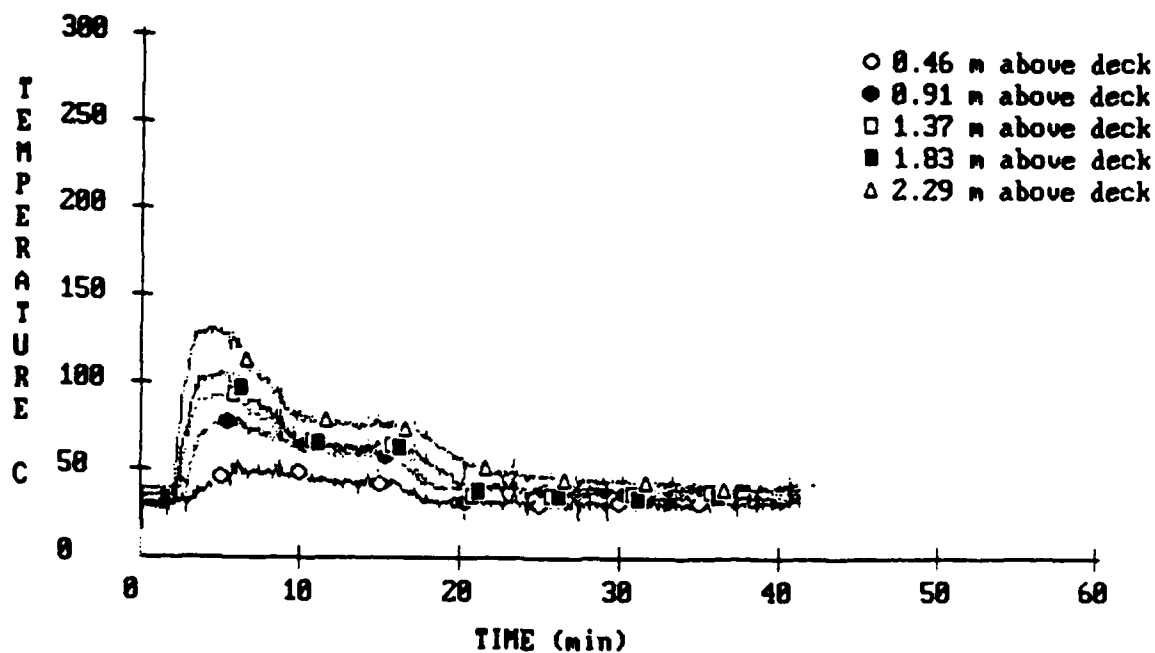


Fig. B-434- Temperature in BERTHING 1 (3-76-2) during Test # 6

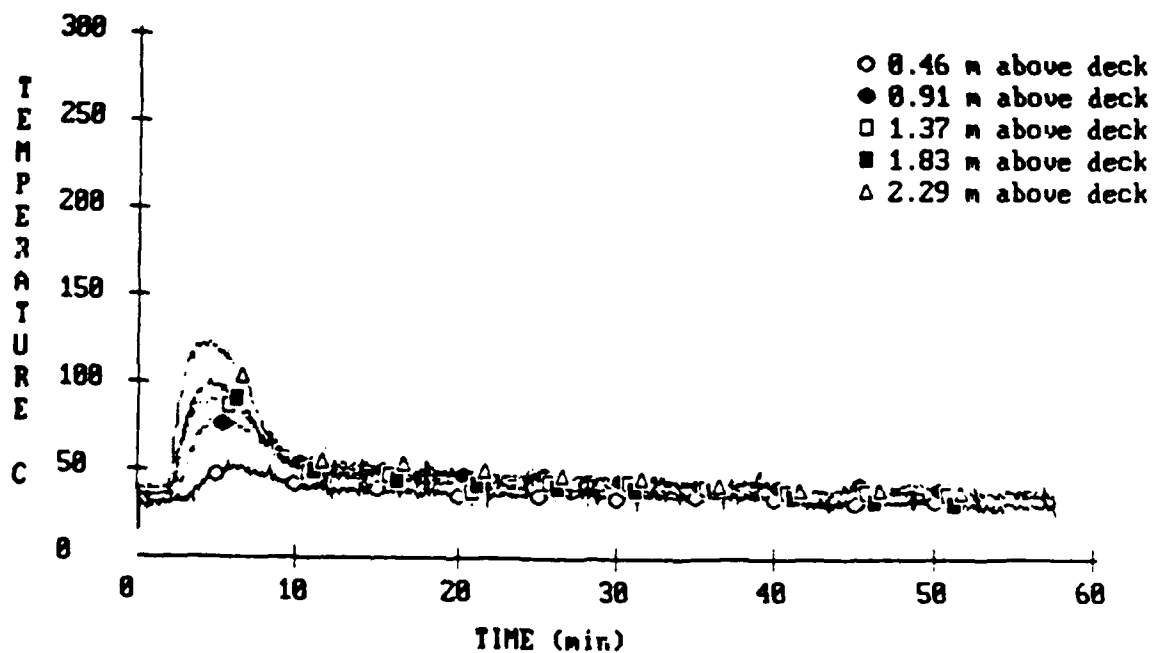


Fig. B-435- Temperature in BERTHING 1 (3-76-2) during Test # 7

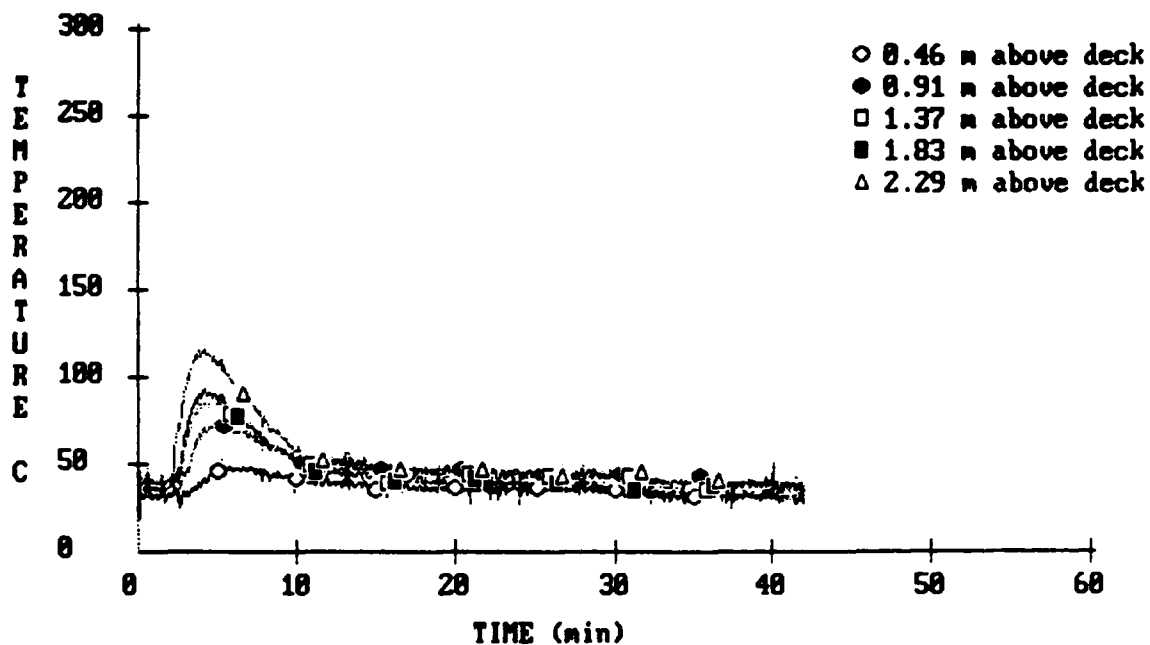


Fig. B-436- Temperature in BERTHING 1 (3-76-2) during Test # 8

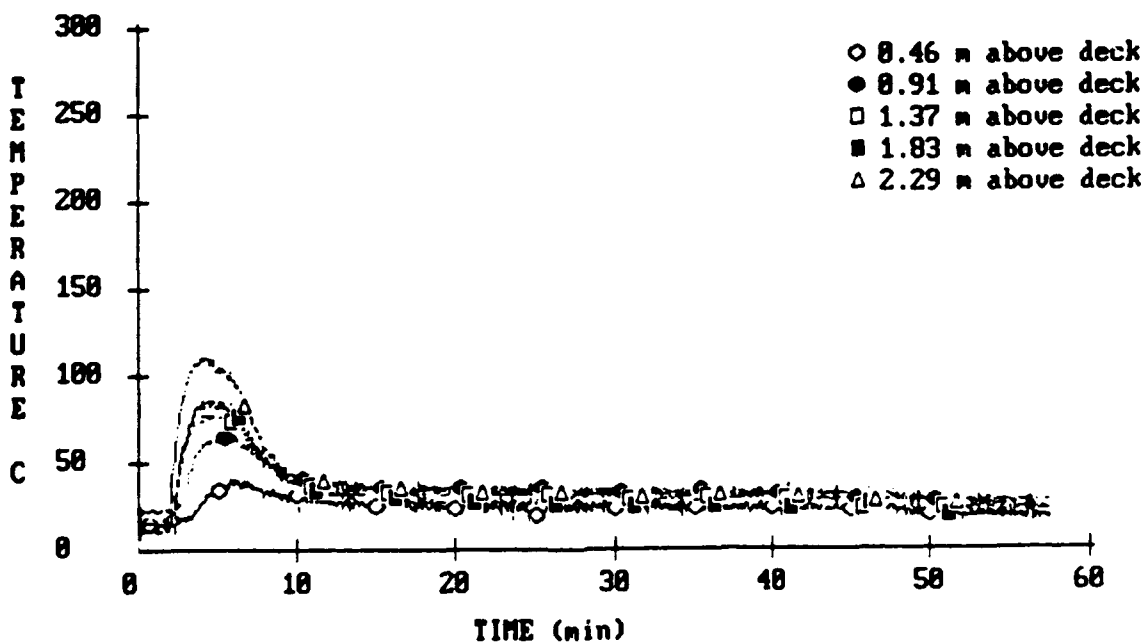


Fig. B-437- Temperature in BERTHING 1 (3-76-2) during Test # 9



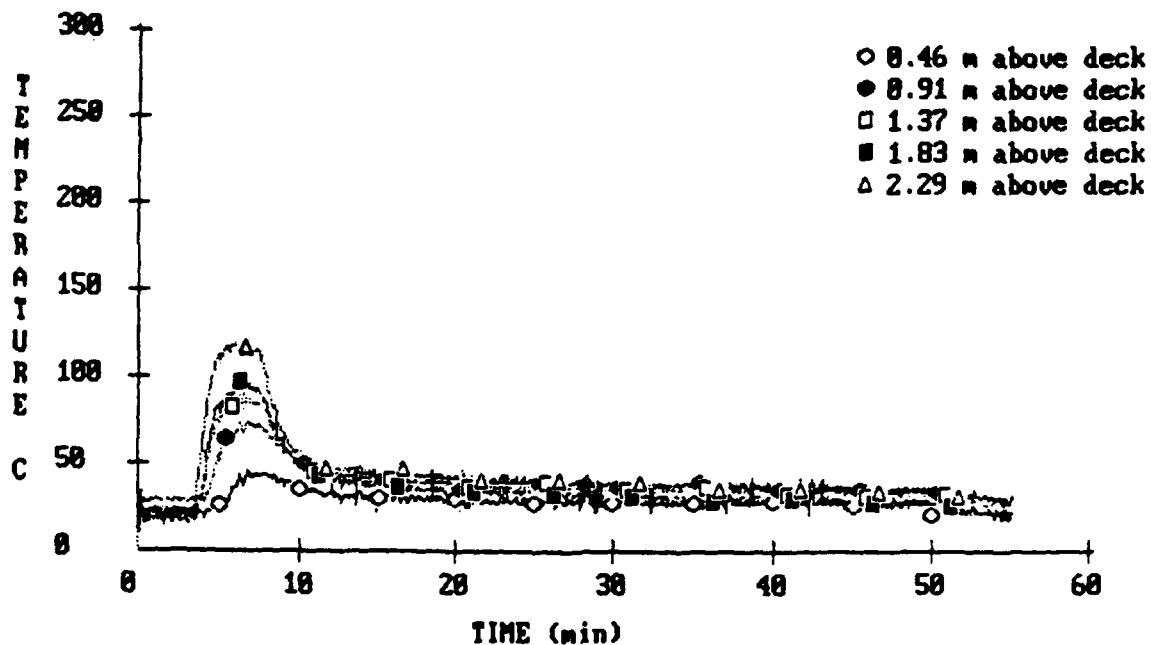


Fig. B-438- Temperature in BERTHING 1 (3-76-2) during Test # 10

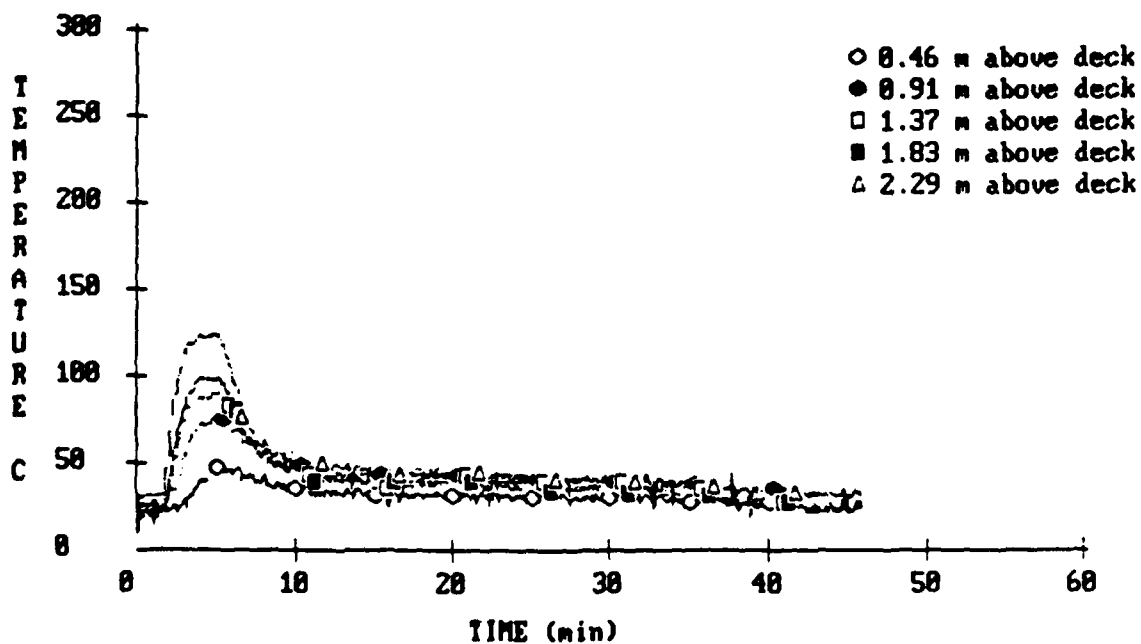


Fig. B-439- Temperature in BERTHING 1 (3-76-2) during Test # 11

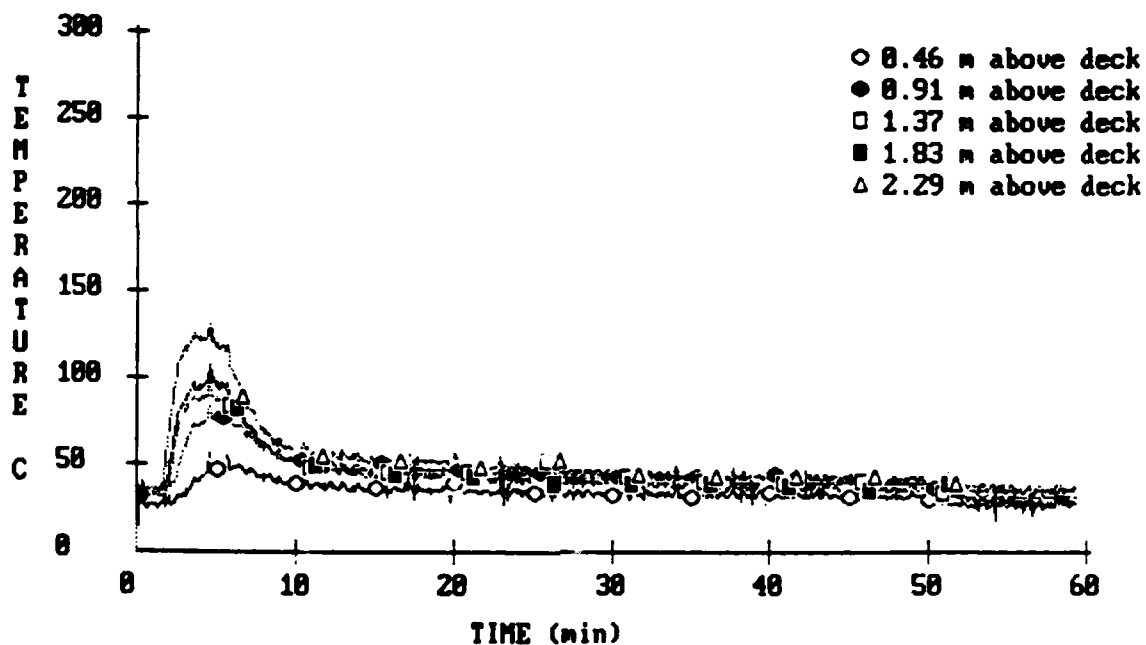


Fig. B-440- Temperature in BERTHING 1 (3-76-2) during Test # 12

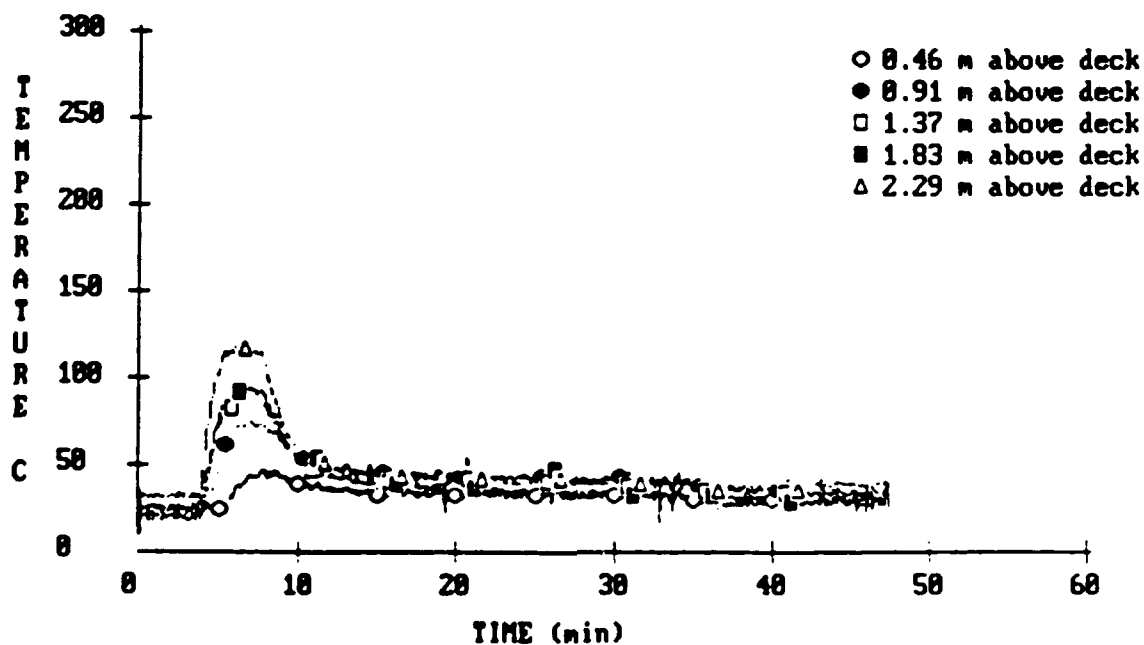


Fig. B-441- Temperature in BERTHING 1 (3-76-2) during Test # 13

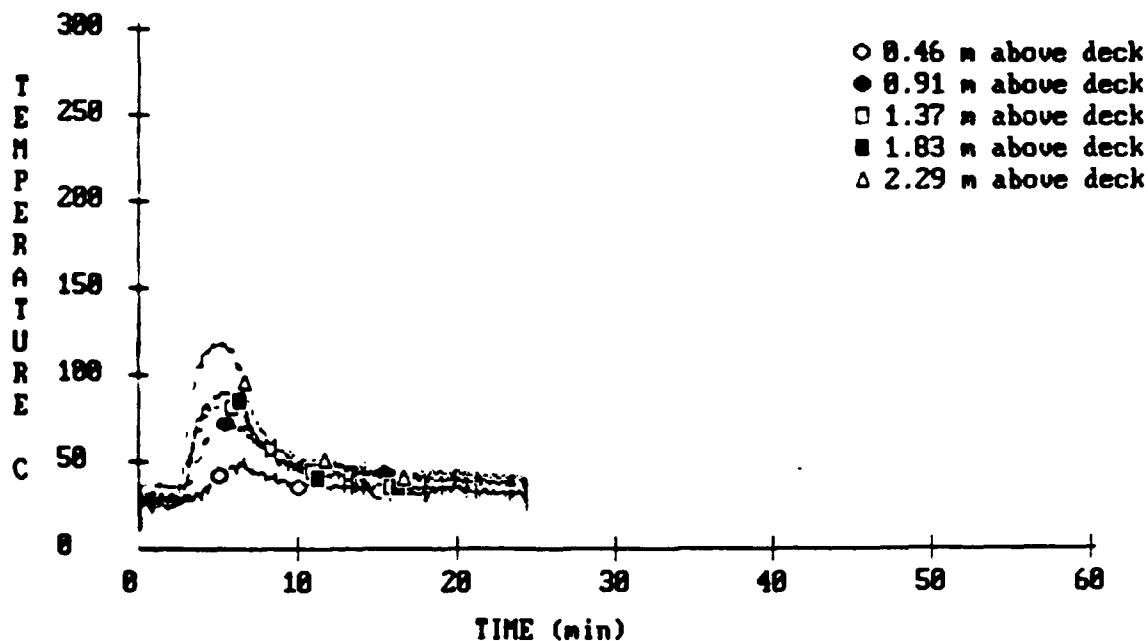


Fig. B-442- Temperature in BERTHING 1 (3-76-2) during Test # 14

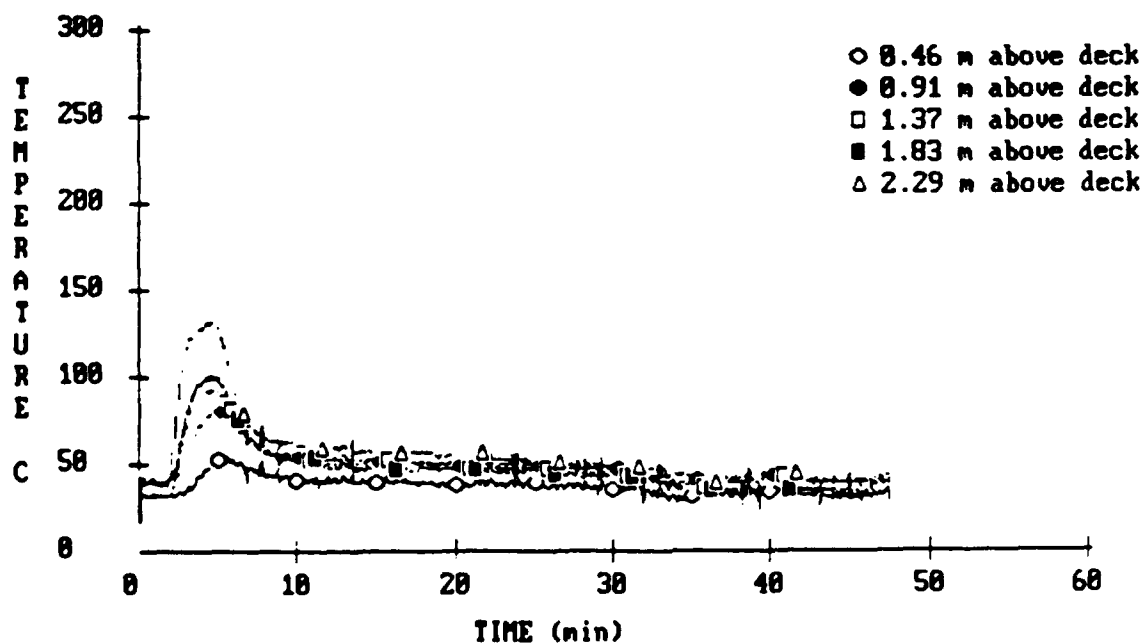


Fig. B-443- Temperature in BERTHING 1 (3-76-2) during Test # 15

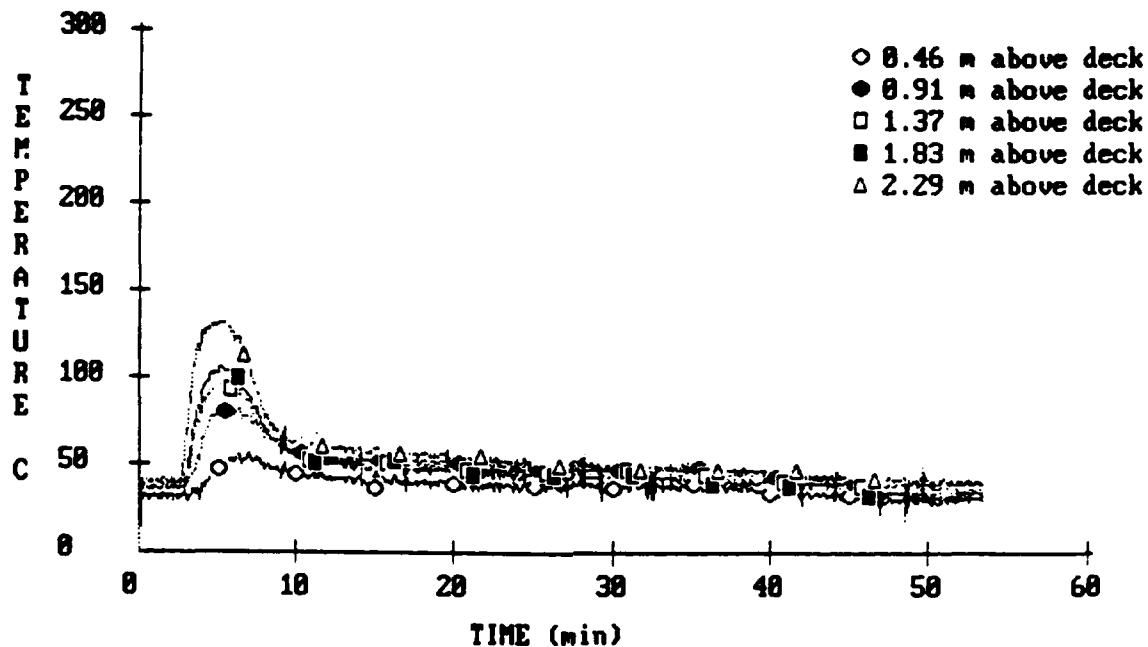


Fig. B-444- Temperature in BERTHING 1 (3-76-2) during Test # 16

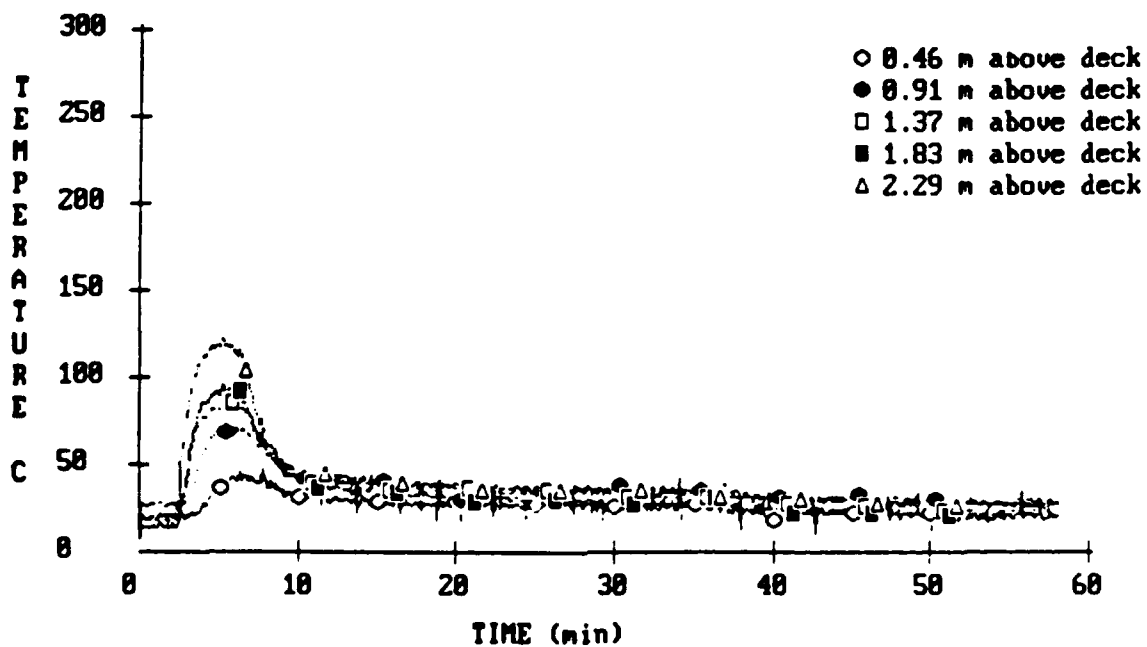


Fig. B-445- Temperature in BERTHING 1 (3-76-2) during Test # 17

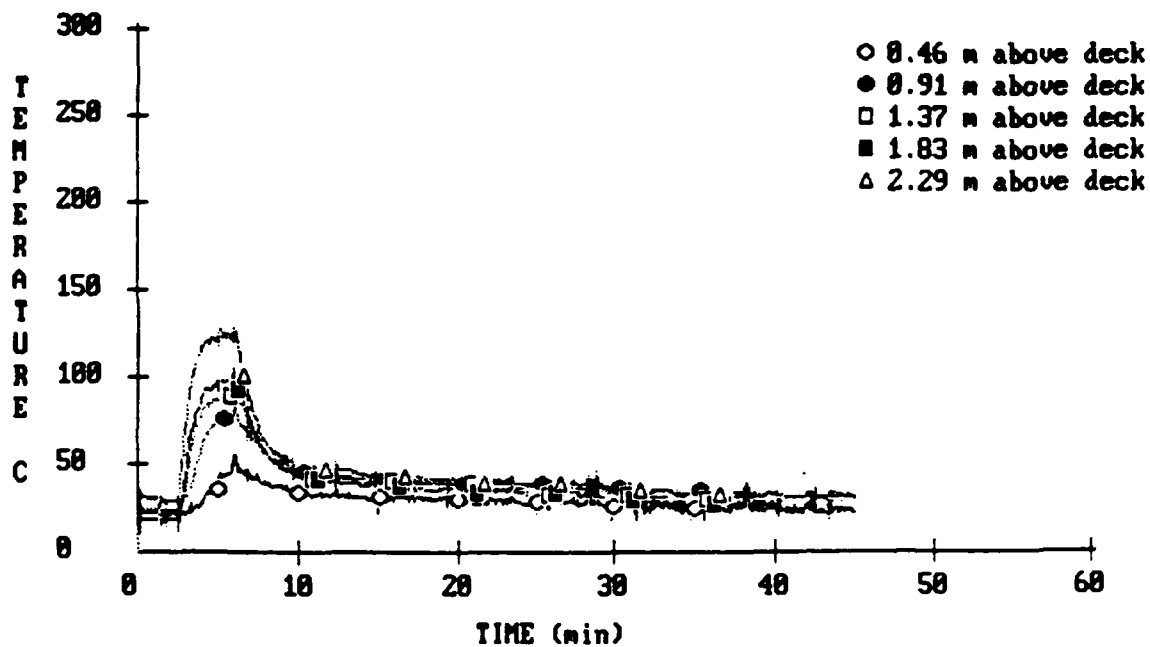


Fig. B-446- Temperature in BERTHING 1 (3-76-2) during Test # 18

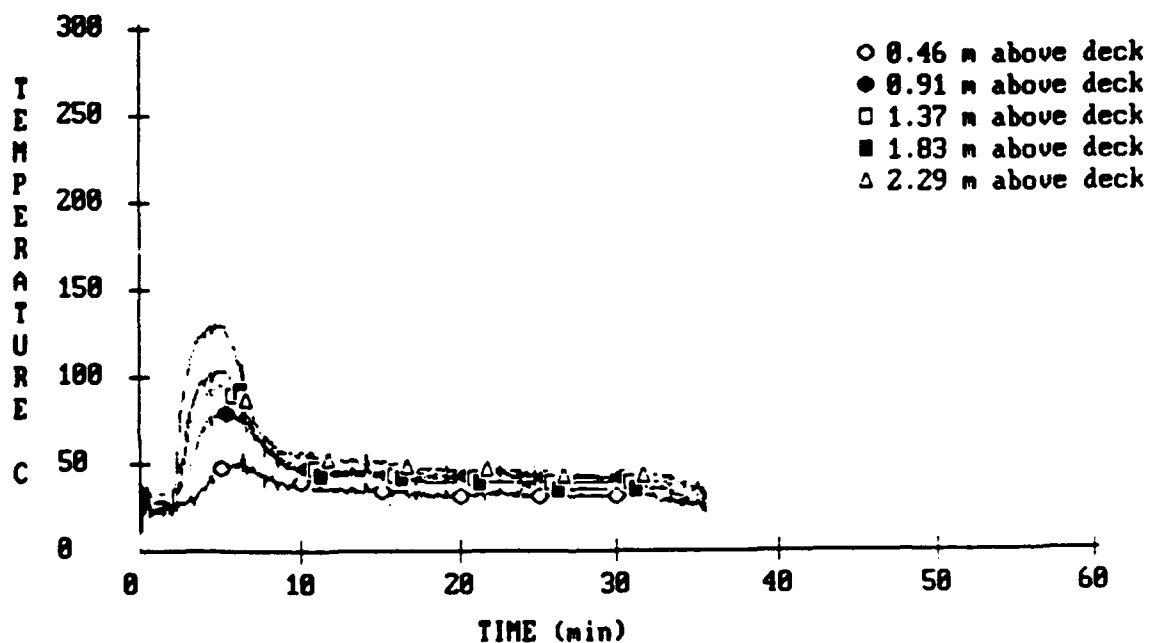


Fig. B-447- Temperature in BERTHING 1 (3-76-2) during Test # 19

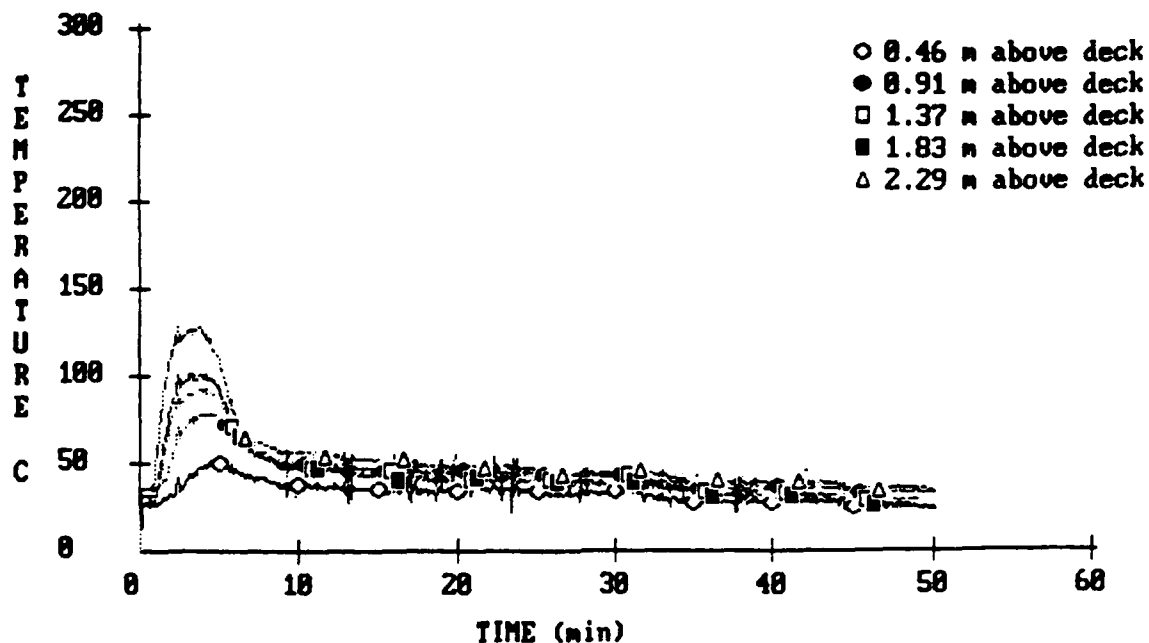


Fig. B-448- Temperature in BERTHING 1 (3-76-2) during Test # 20

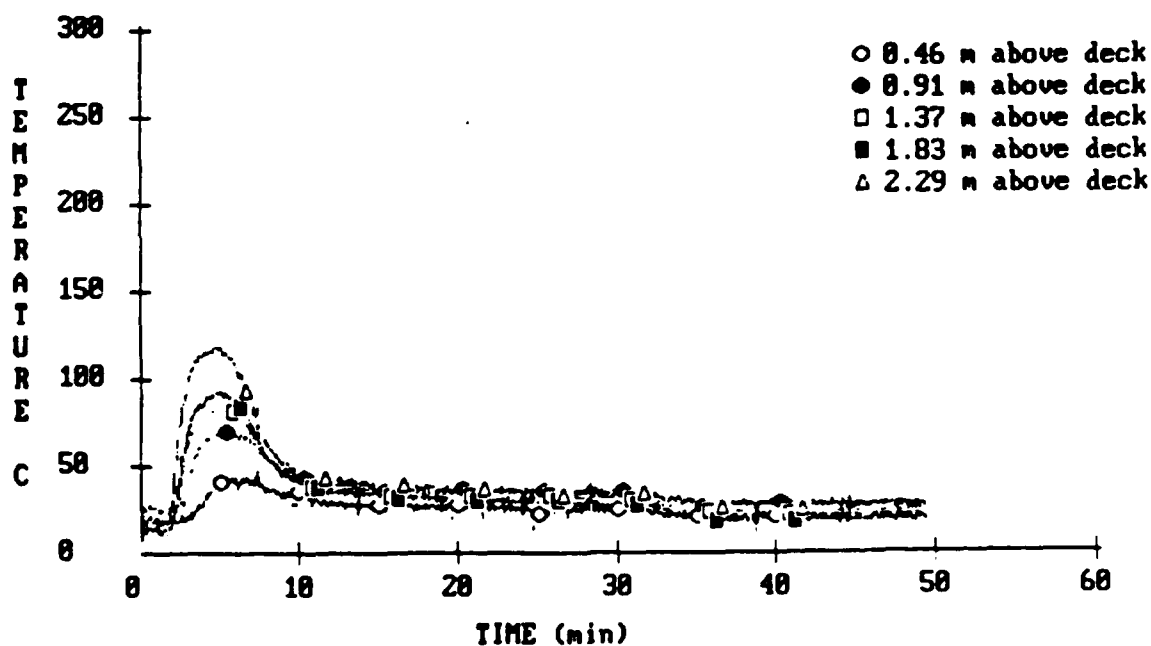


Fig. B-449- Temperature in BERTHING 1 (3-76-2) during Test # 21

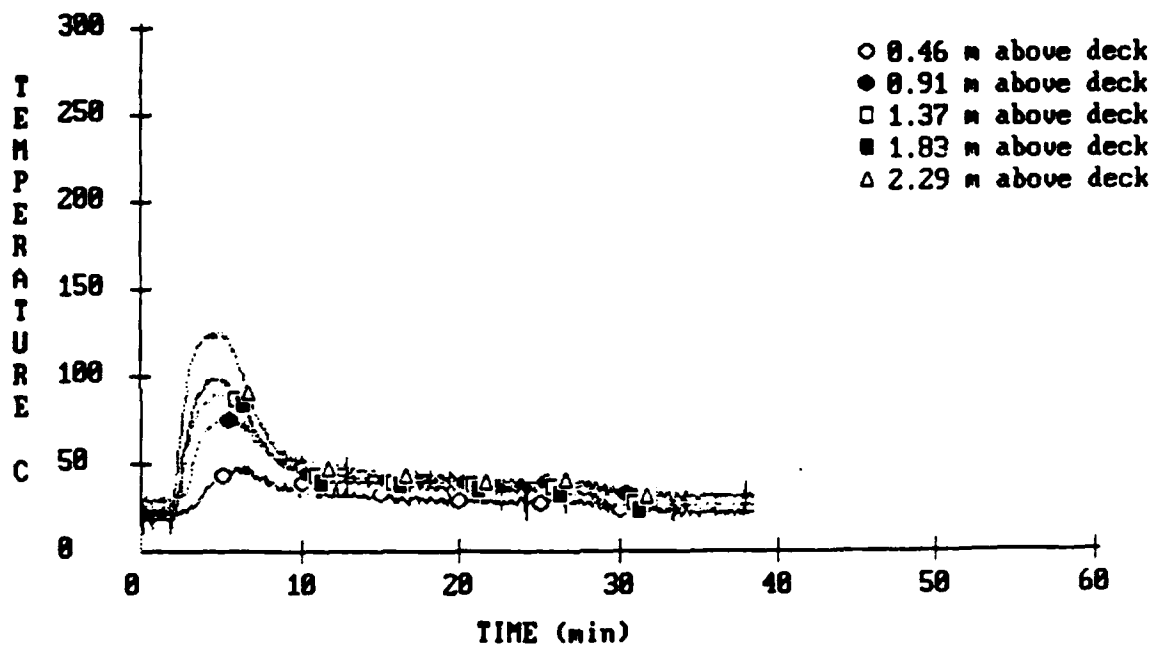


Fig. B-450- Temperature in BERTHING 1 (3-76-2) during Test # 22

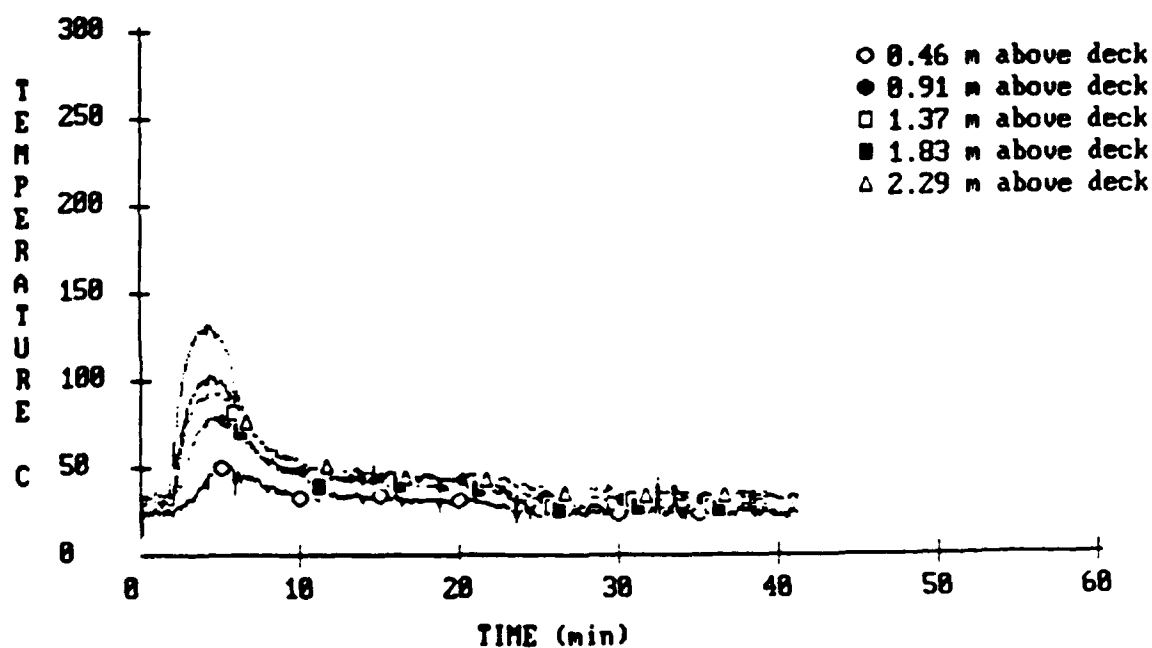


Fig. B-451- Temperature in BERTHING 1 (3-76-2) during Test # 23

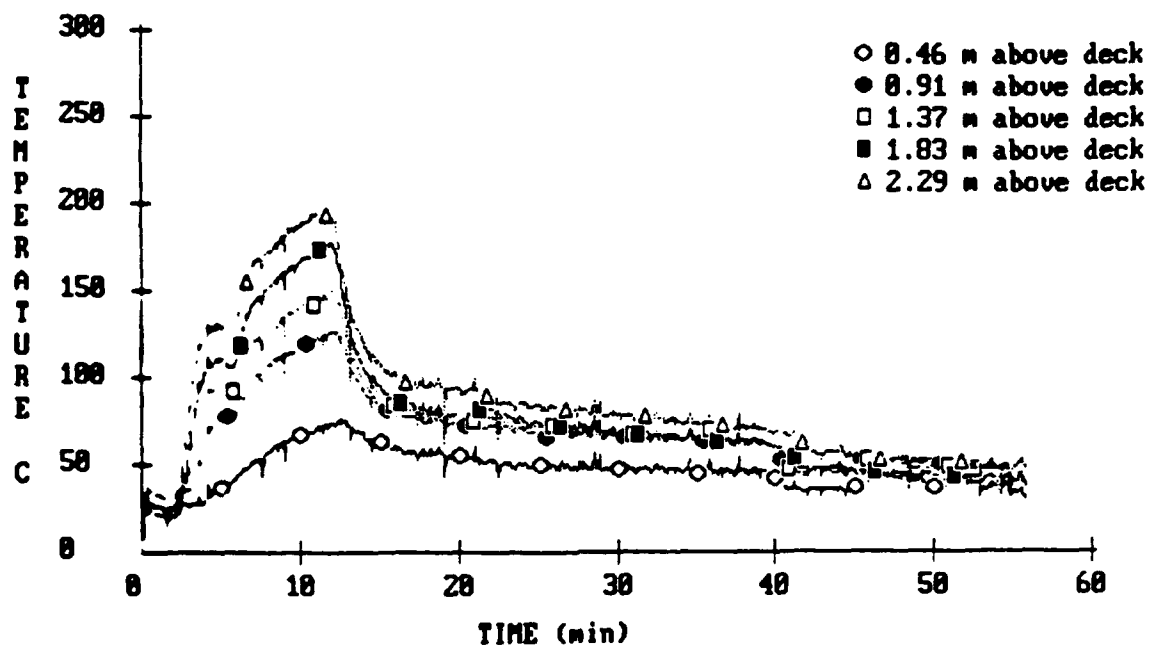


Fig. B-452- Temperature in BERTHING 1 (3-76-2) during Test # 24

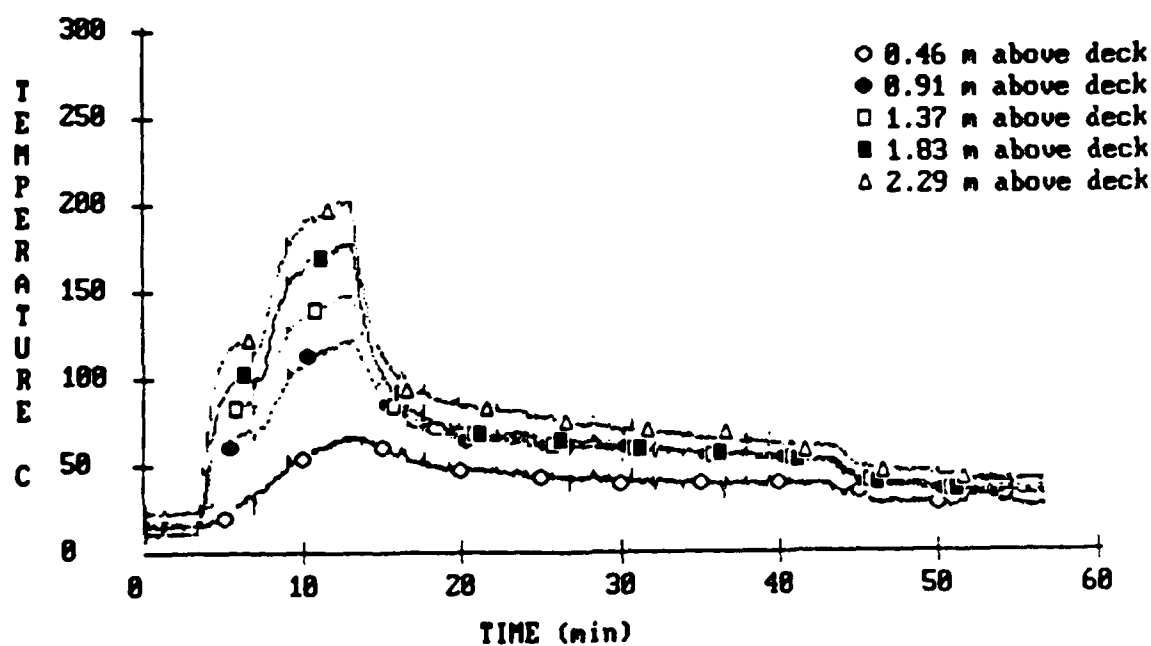


Fig. B-453- Temperature in BERTHING 1 (3-76-2) during Test # 25



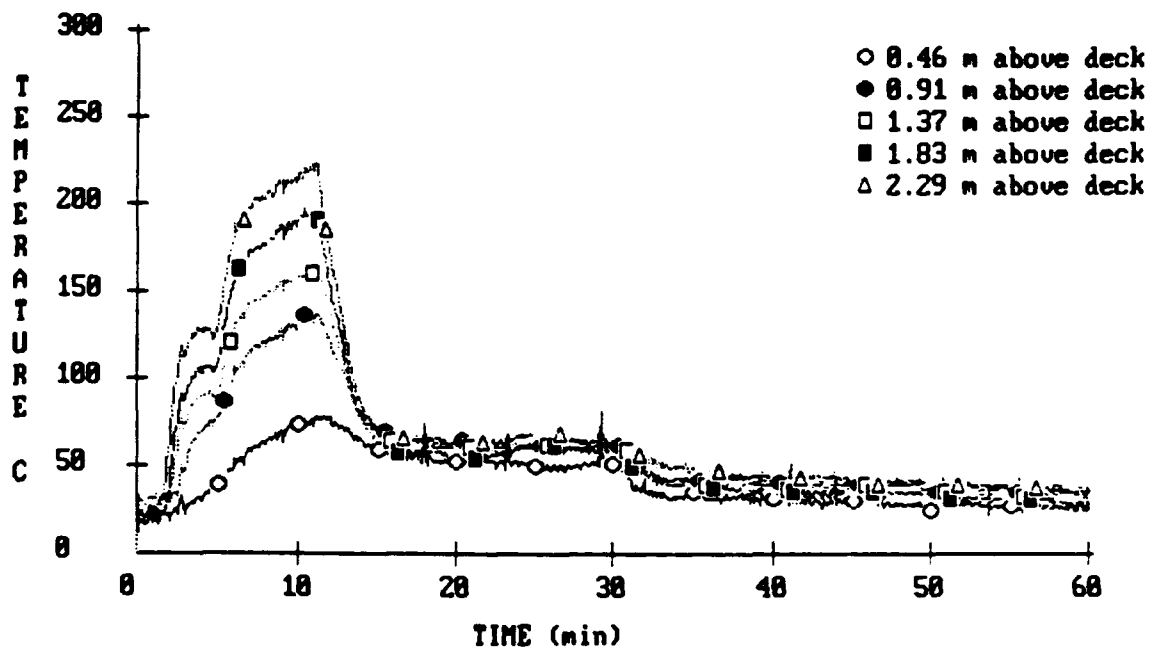


Fig. B-454- Temperature in BERTHING 1 (3-76-2) during Test # 26

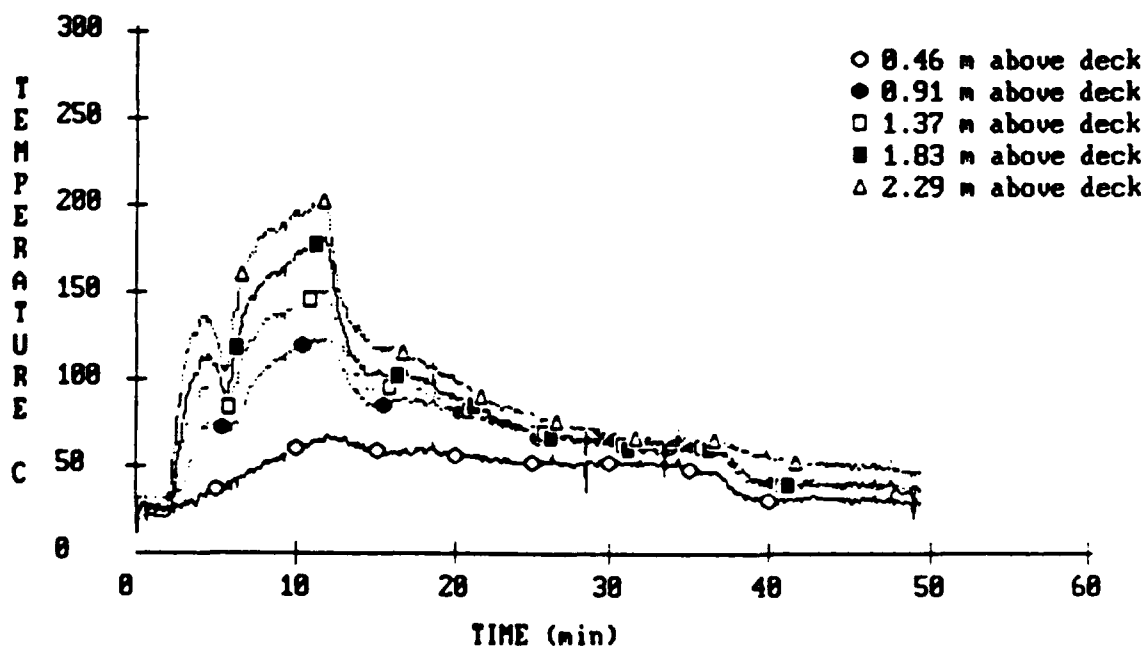


Fig. B-455- Temperature in BERTHING 1 (3-76-2) during Test # 27

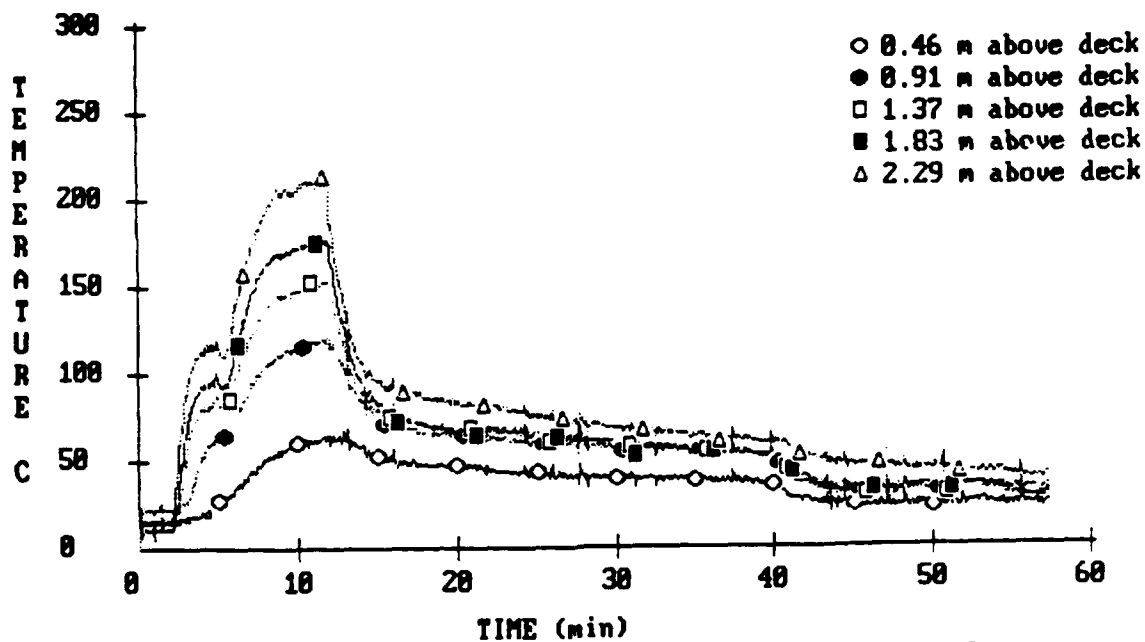


Fig. B-456- Temperature in BERTHING 1 (3-76-2) during Test # 28

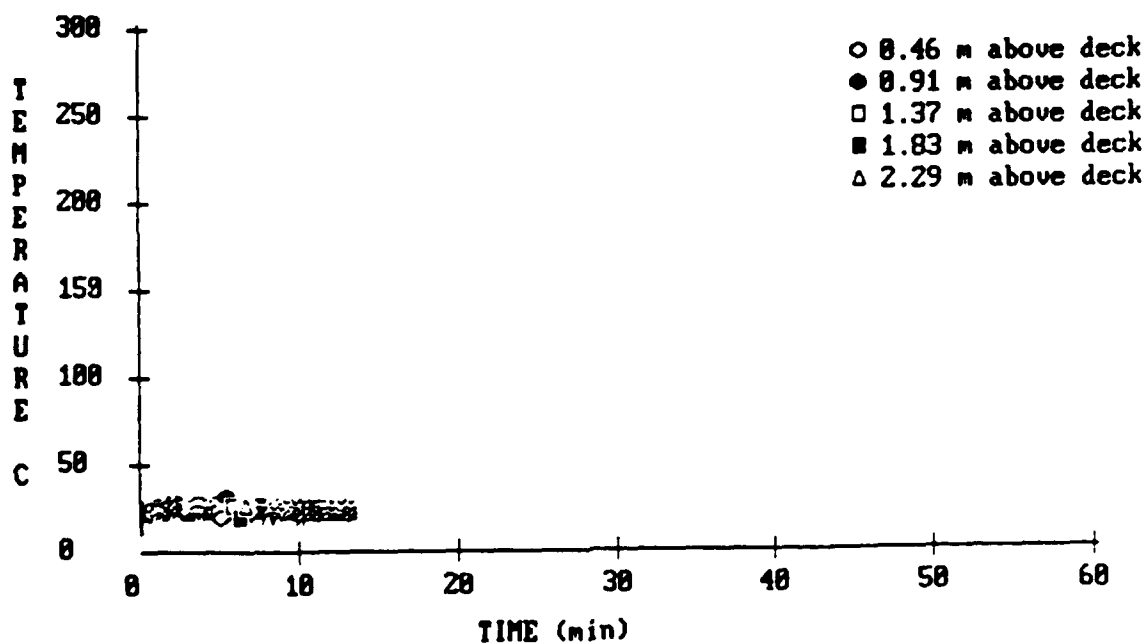


Fig. B-457- Temperature in BERTHING 1 (3-76-2) during Test # 29

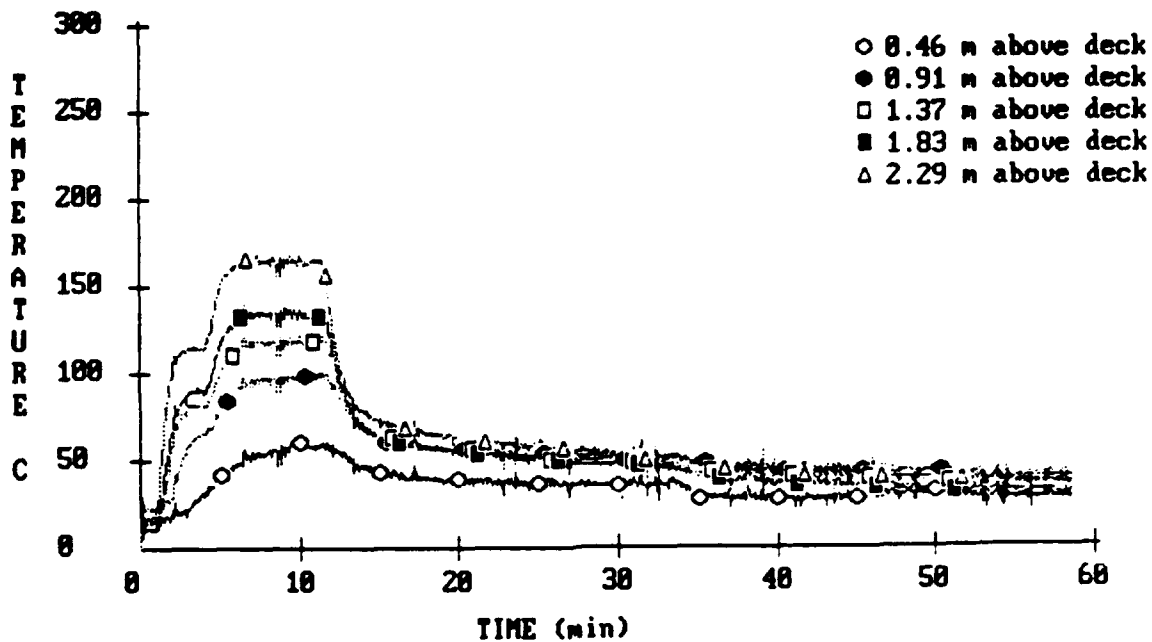


Fig. B-458- Temperature in BERTHING 1 (3-76-2) during Test # 30

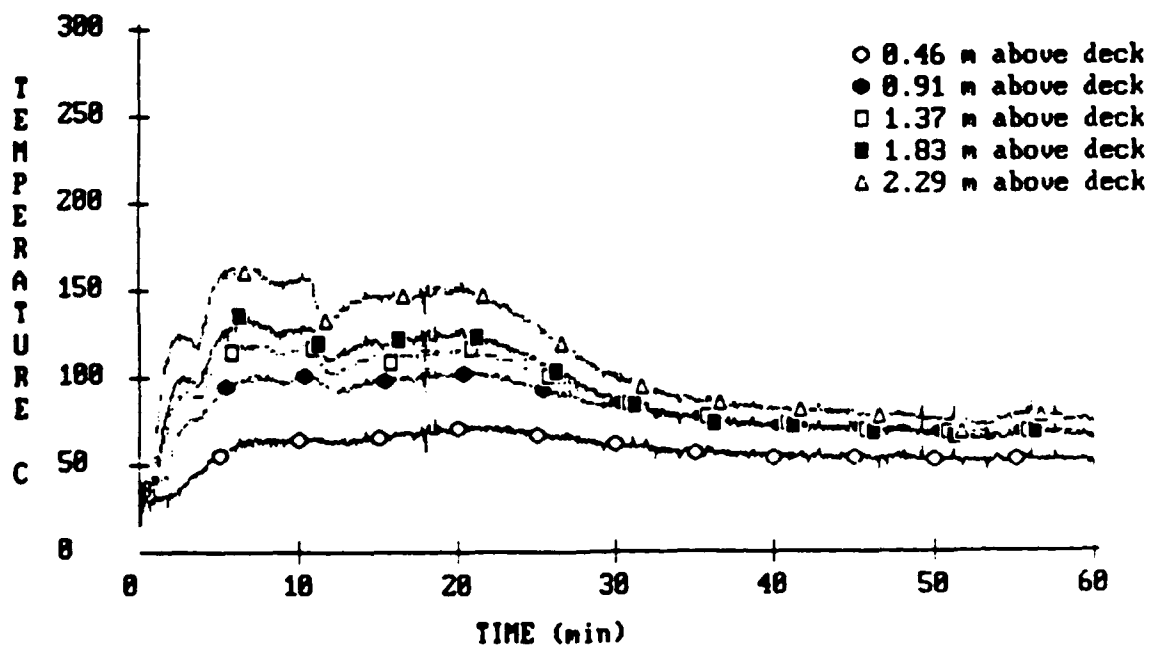


Fig. B-459- Temperature in BERTHING 1 (3-76-2) during Test # 31

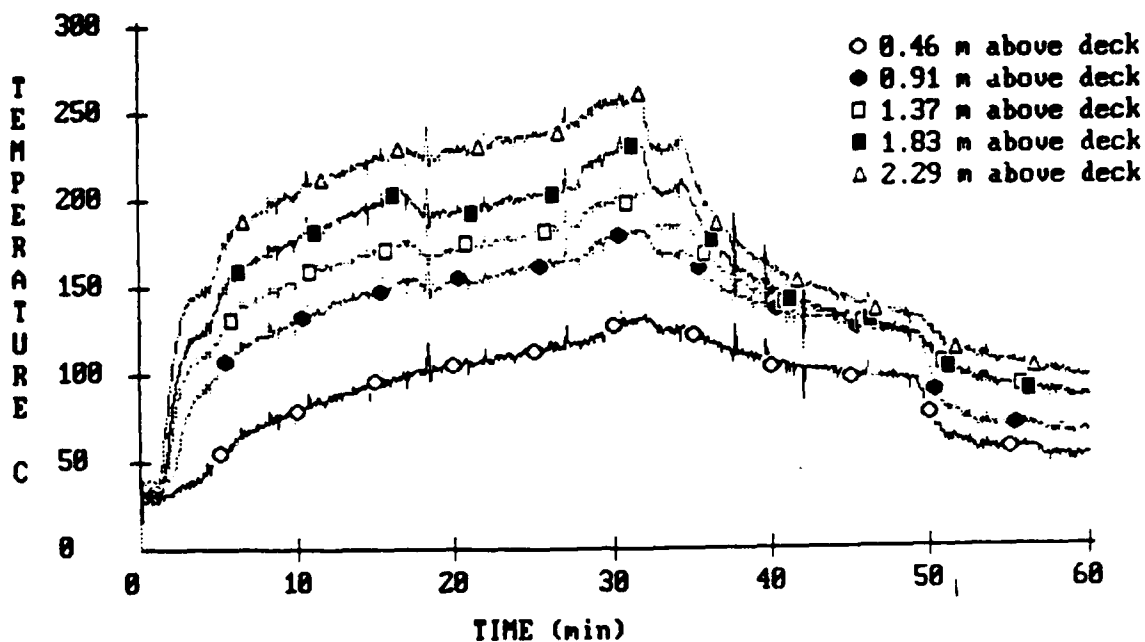


Fig. B-460- Temperature in BERTHING 1 (3-76-2) during Test # 32

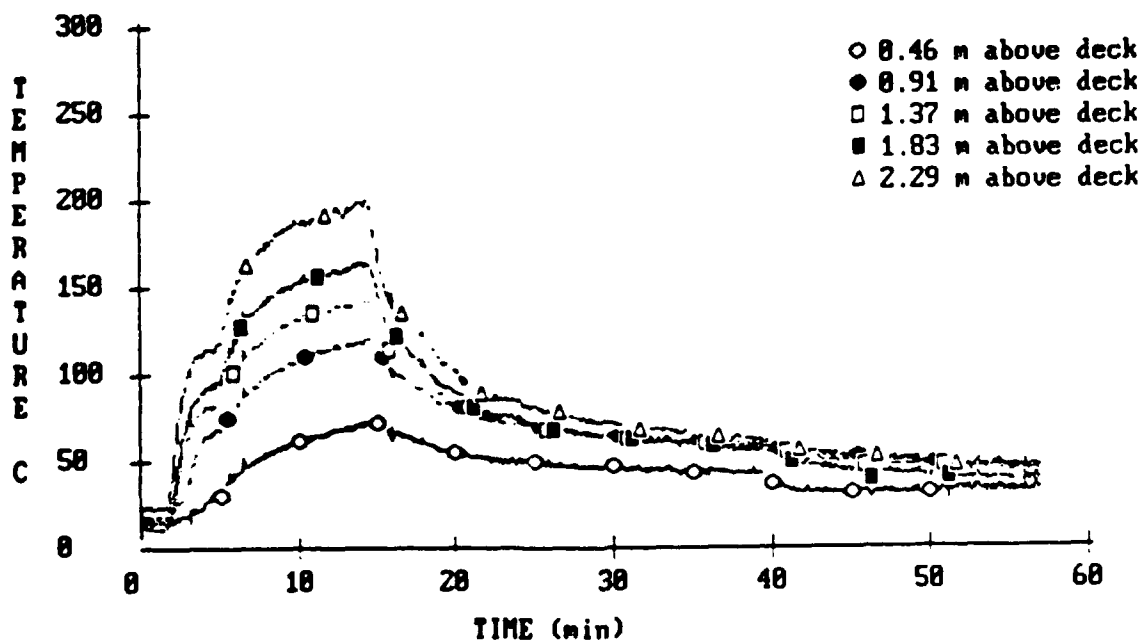


Fig. B-461- Temperature in BERTHING 1 (3-76-2) during Test # 33

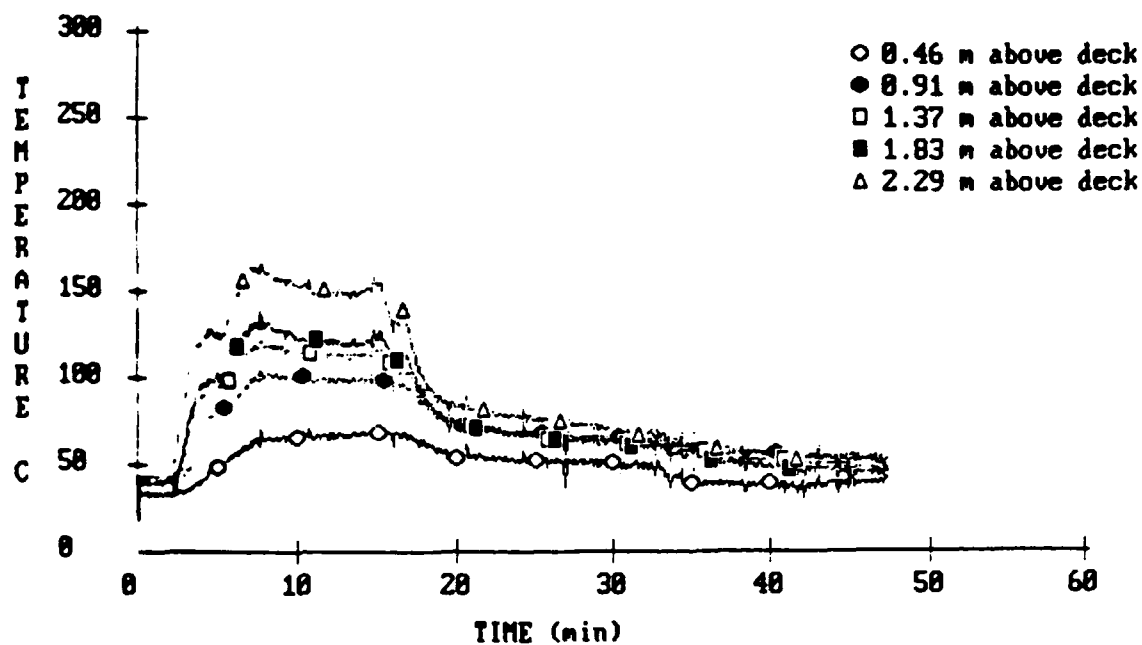


Fig. B-462- Temperature in BERTHING 1 (3-76-2) during Test # 34

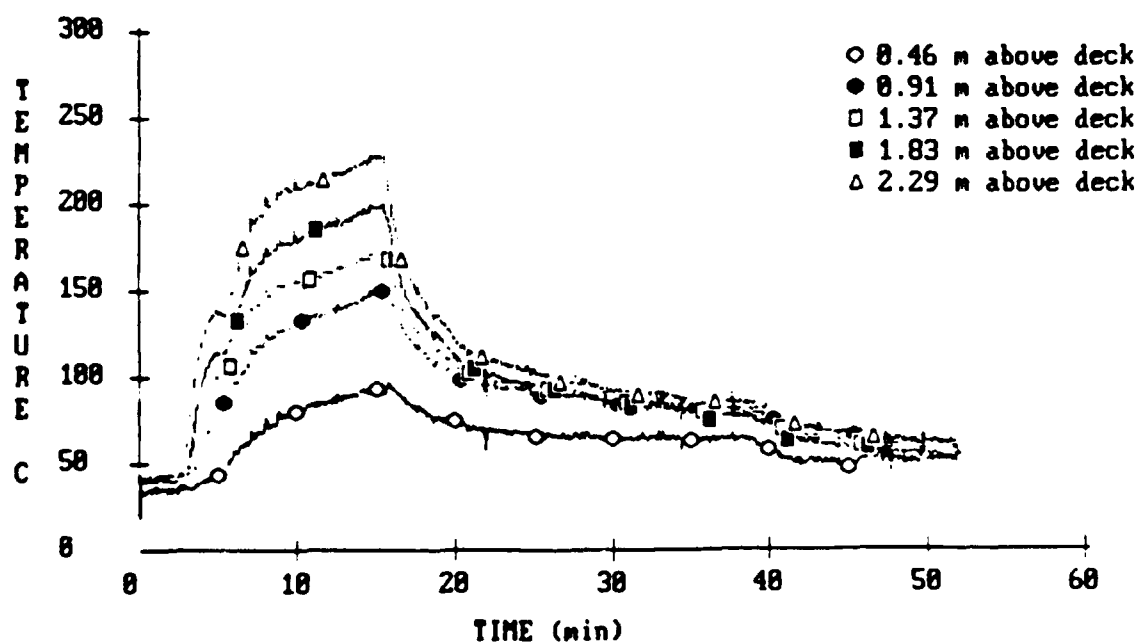


Fig. B Temperature in BERTHING 1 (3-76-2) during Test # 35

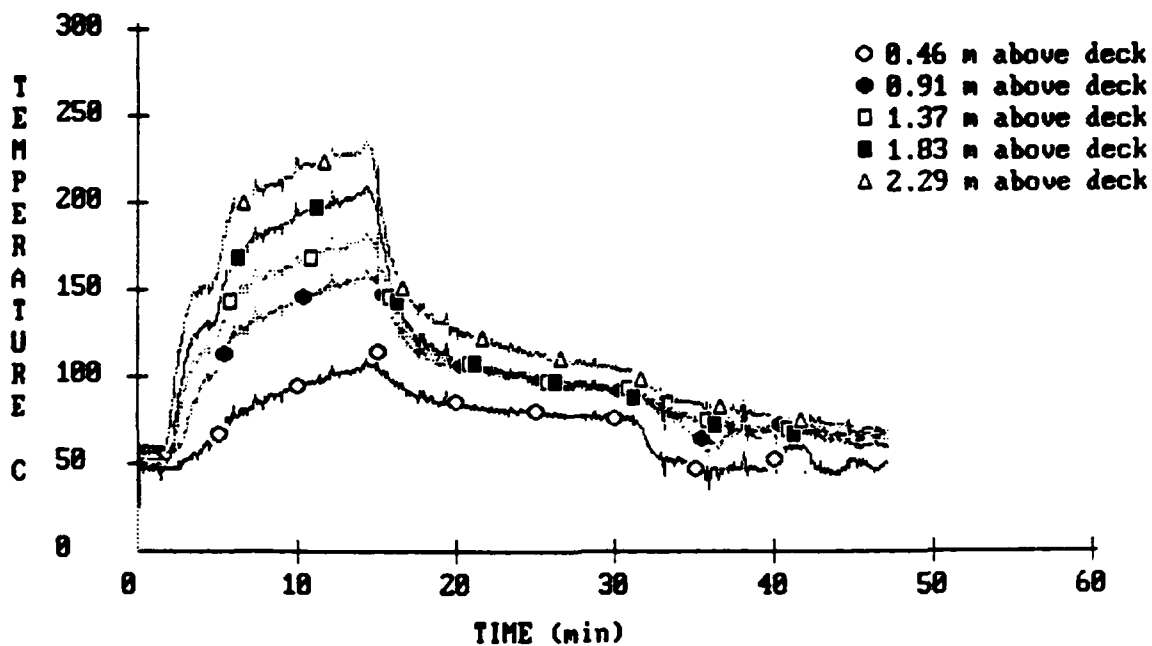


Fig. B-464- Temperature in BERTHING 1 (3-76-2) during Test # 36

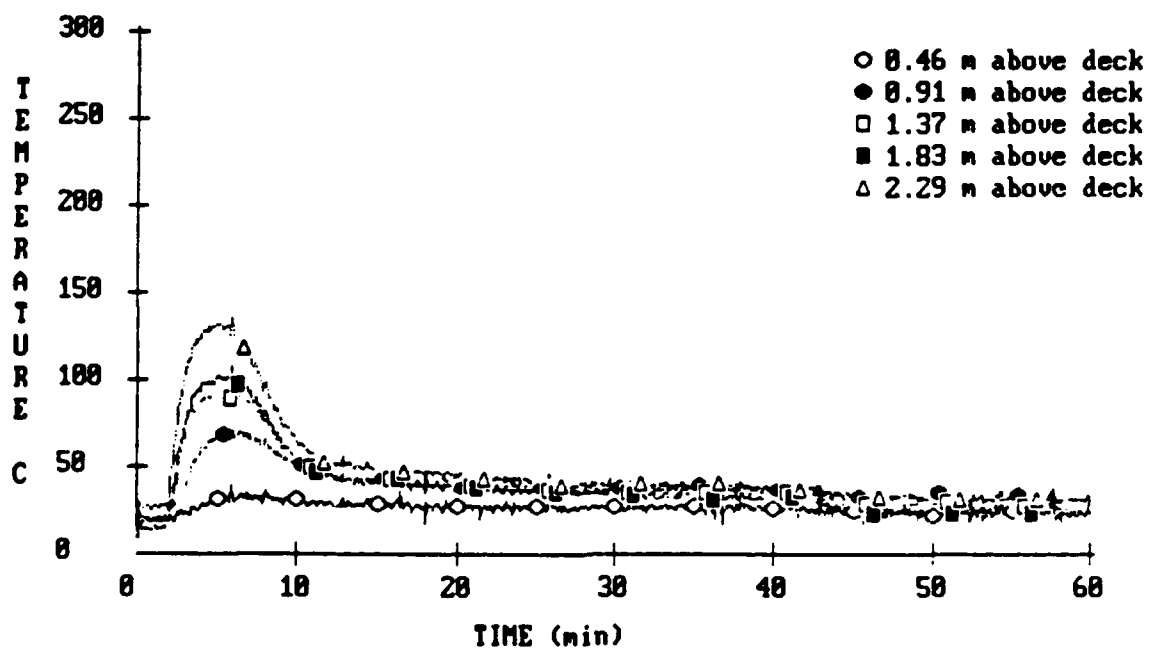


Fig. B-465- Temperature in BERTHING 1 (3-76-2) during Test # 37

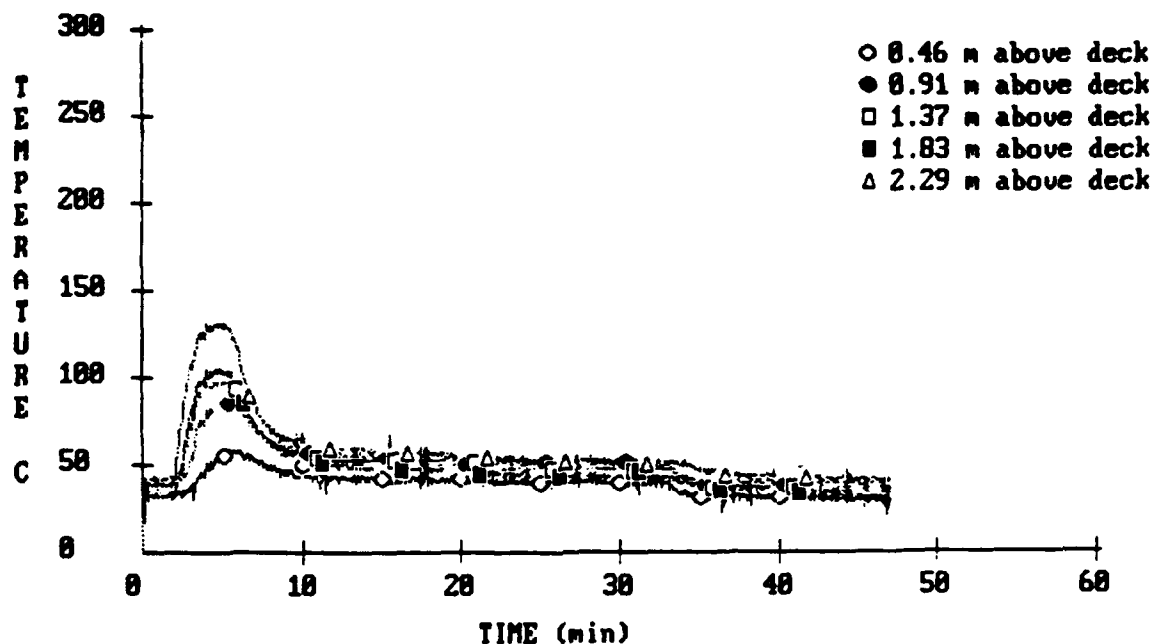


Fig. B-468- Temperature in BERTHING 1 (3-76-2) during Test # 48

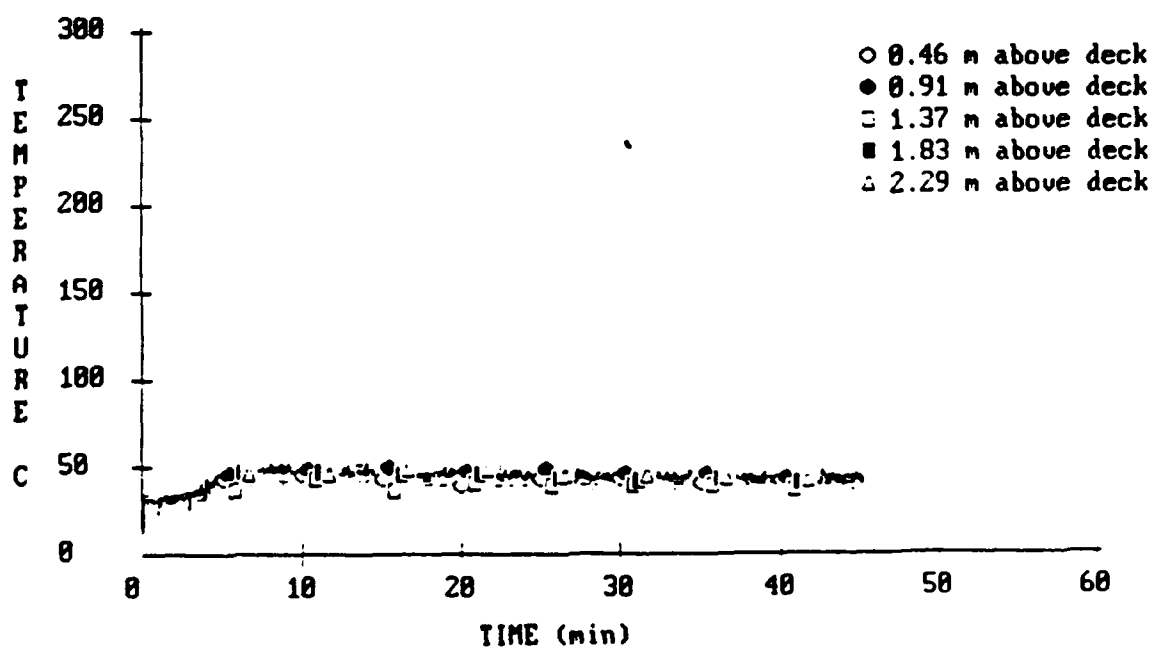


Fig. B-469- Temperature in RICER 2 (2-86-2) during Test # 2

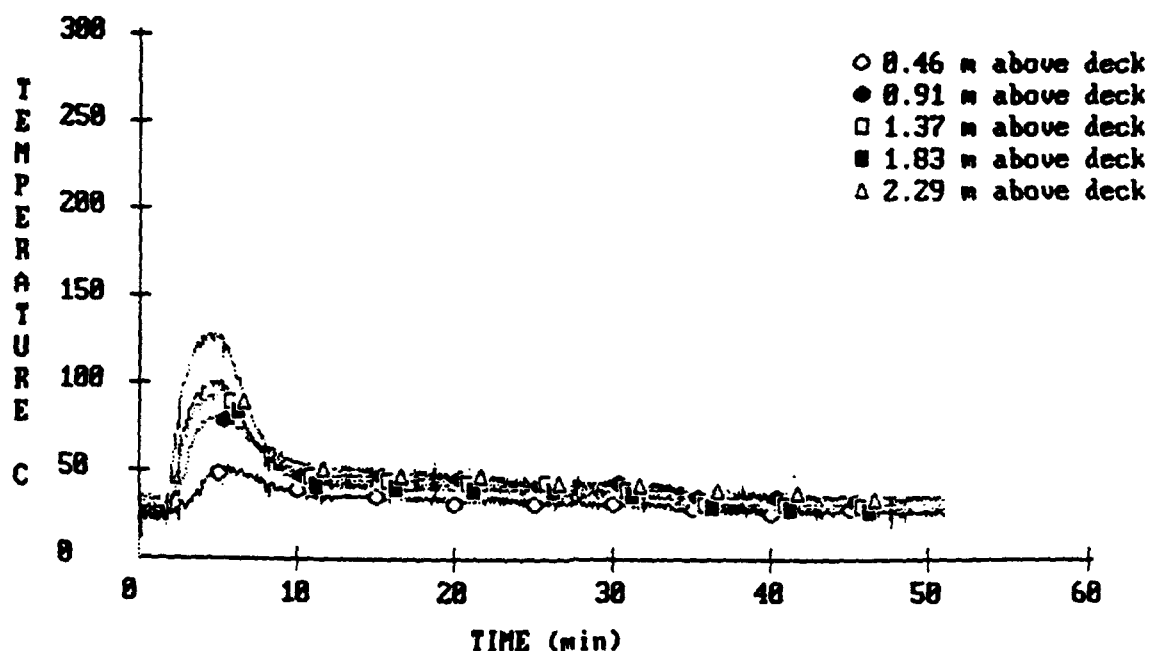


Fig. B-466- Temperature in BERTHING 1 (3-76-2) during Test # 38

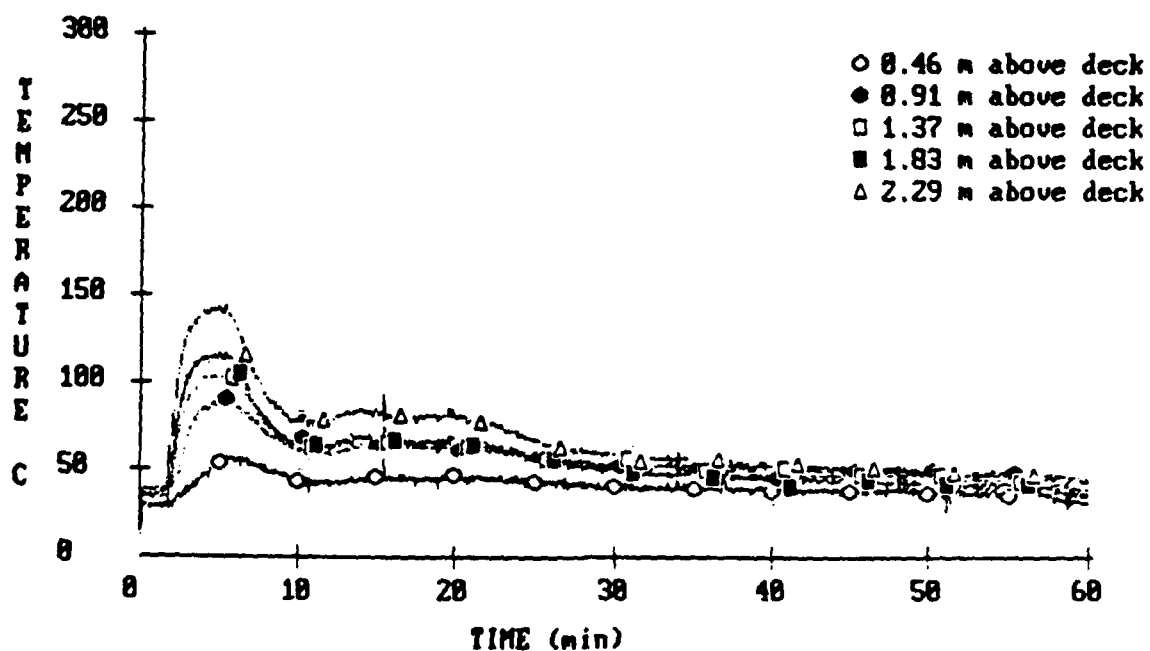


Fig. B-467- Temperature in BERTHING 1 (3-76-2) during Test # 39



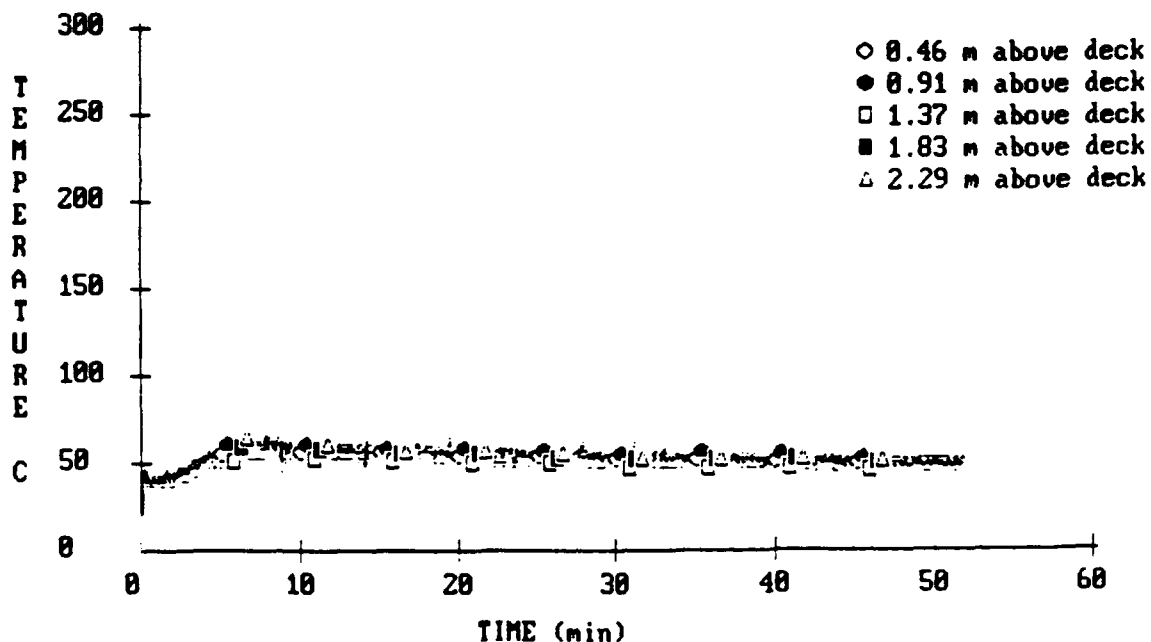


Fig. B-470- Temperature in RICER 2 (2-86-2) during Test # 3

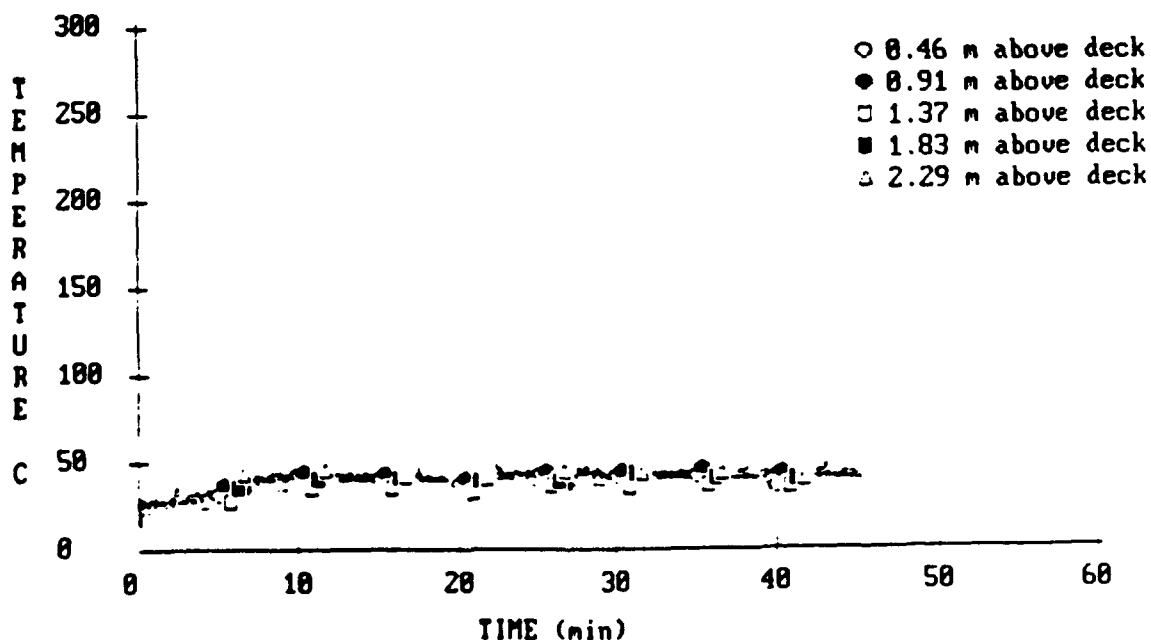


Fig. B-471- Temperature in RICER 2 (2-86-2) during Test # 4

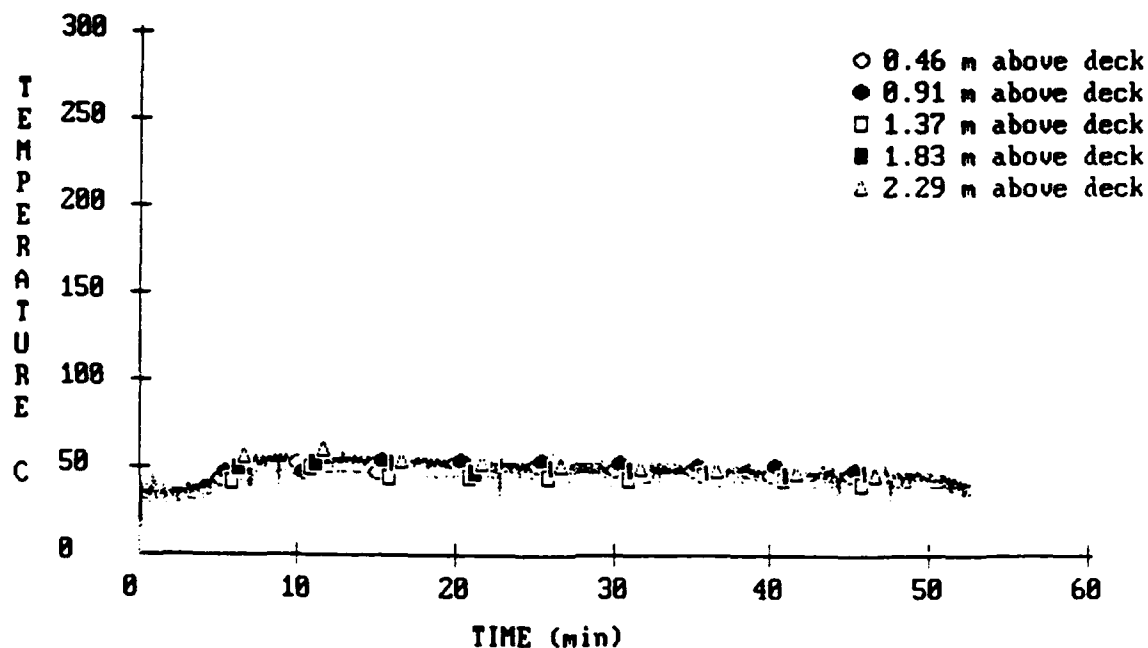


Fig. B-472- Temperature in RICER 2 (2-86-2) during Test # 5

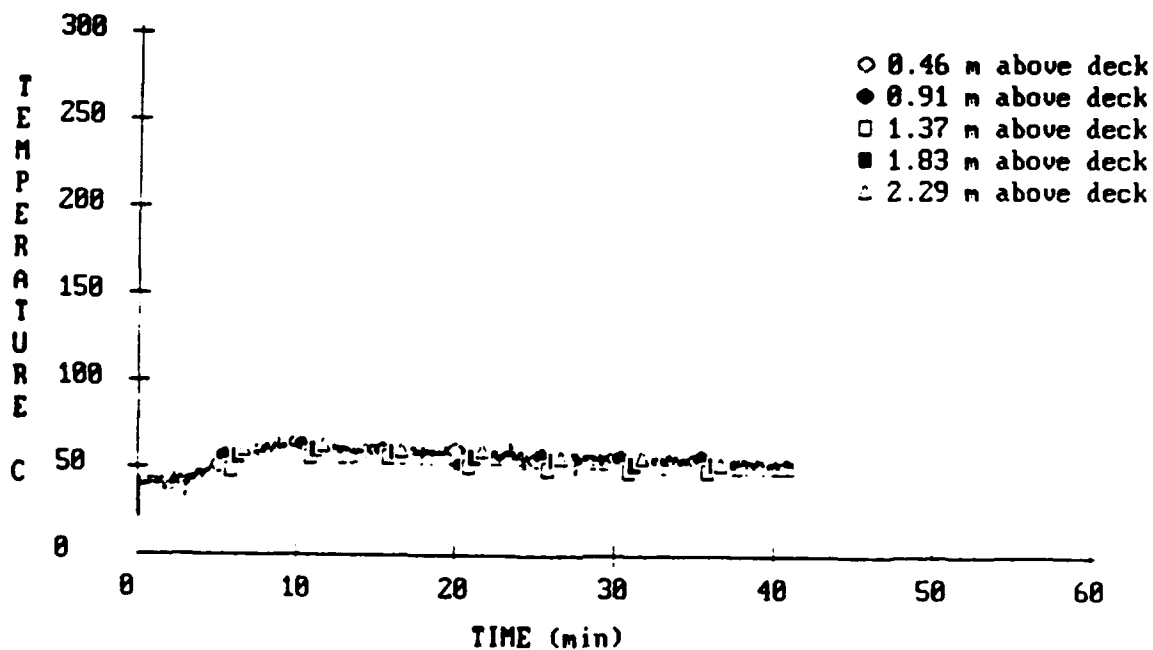


Fig. B-473- Temperature in RICER 2 (2-86-2) during Test # 6

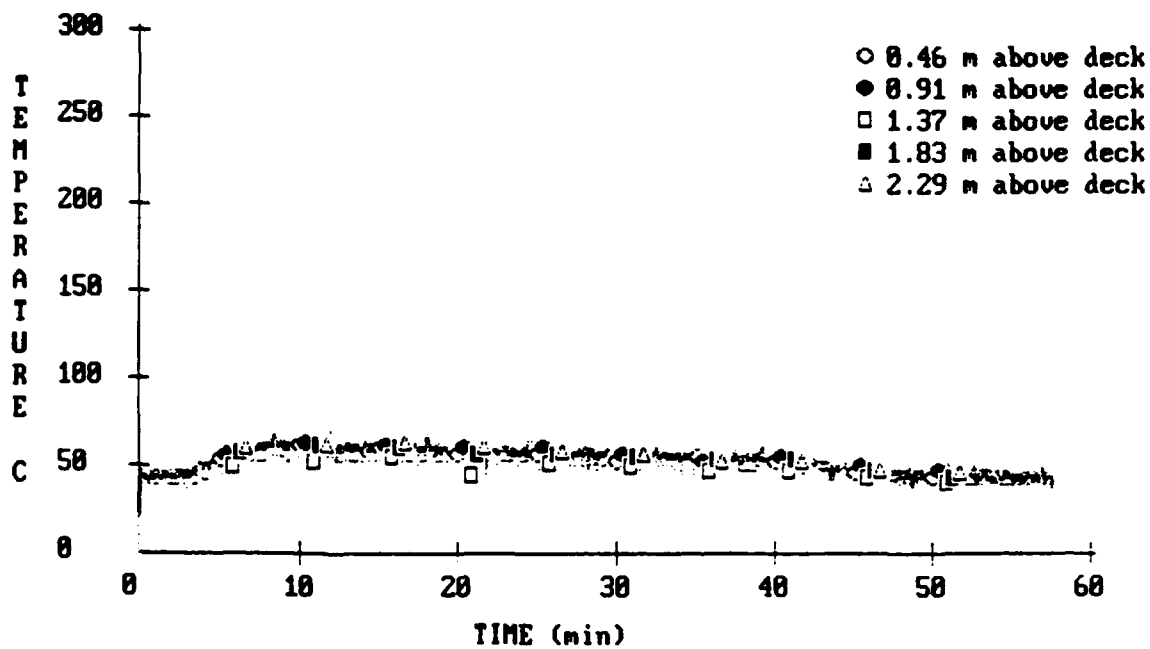


Fig. B-474- Temperature in RICER 2 (2-86-2) during Test # 7

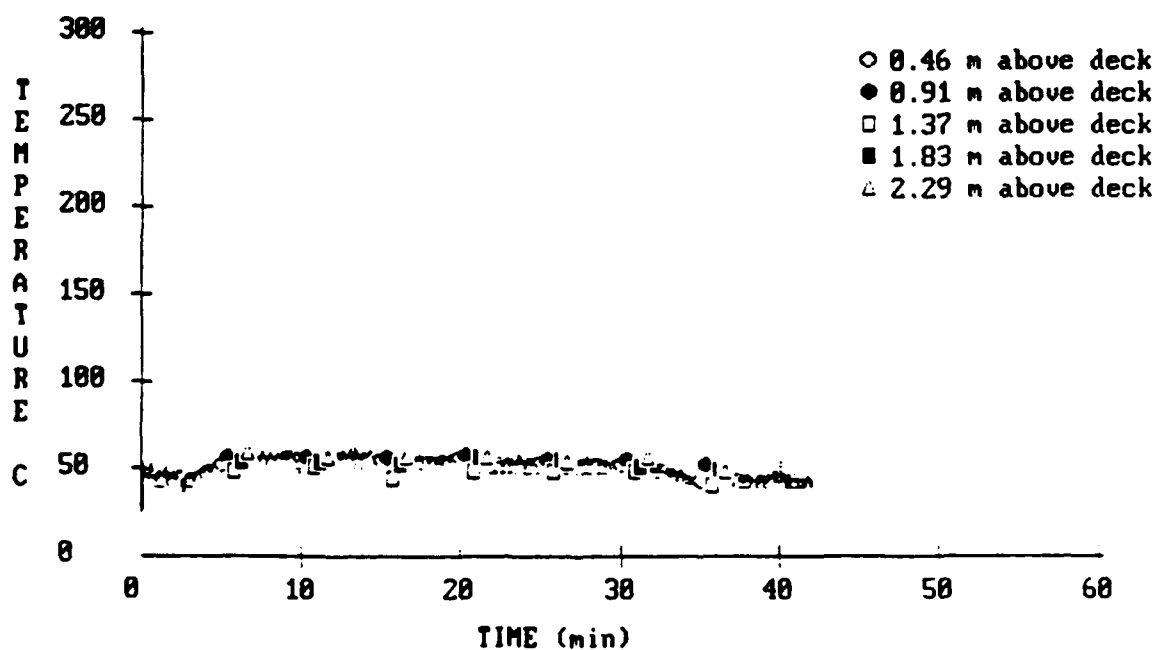


Fig. B-475- Temperature in RICER 2 (2-86-2) during Test # 8

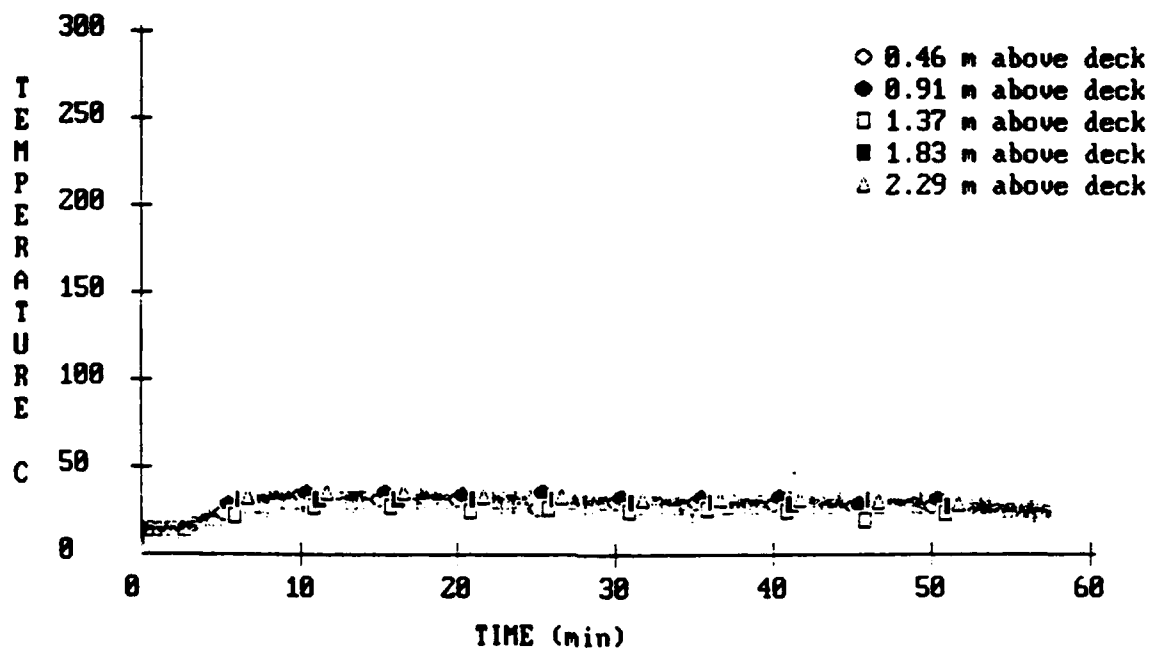


Fig. B-476- Temperature in RICER 2 (2-86-2) during Test # 9

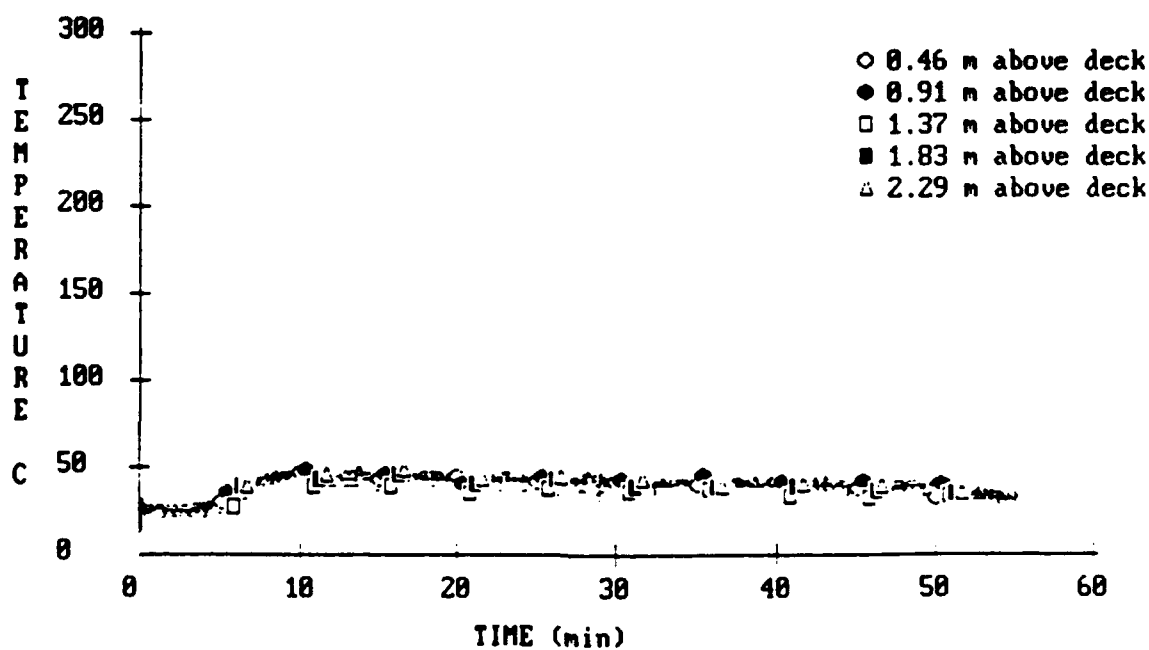


Fig. B-477- Temperature in RICER 2 (2-86-2) during Test # 10

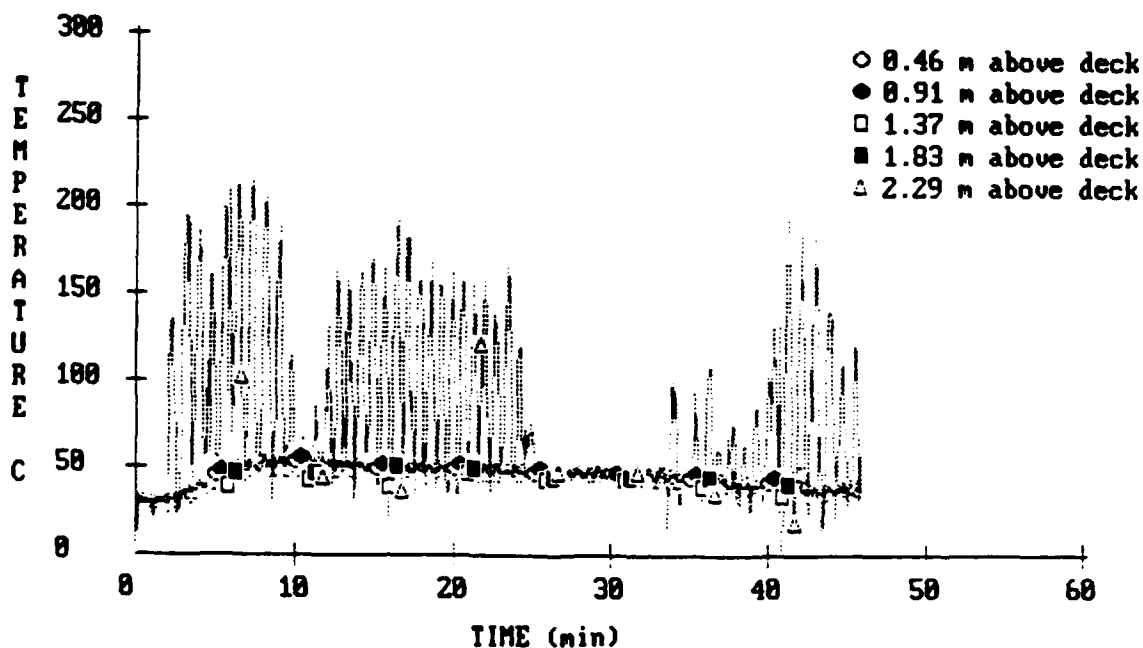


Fig. B-478- Temperature in RICER 2 (2-86-2) during Test # 11

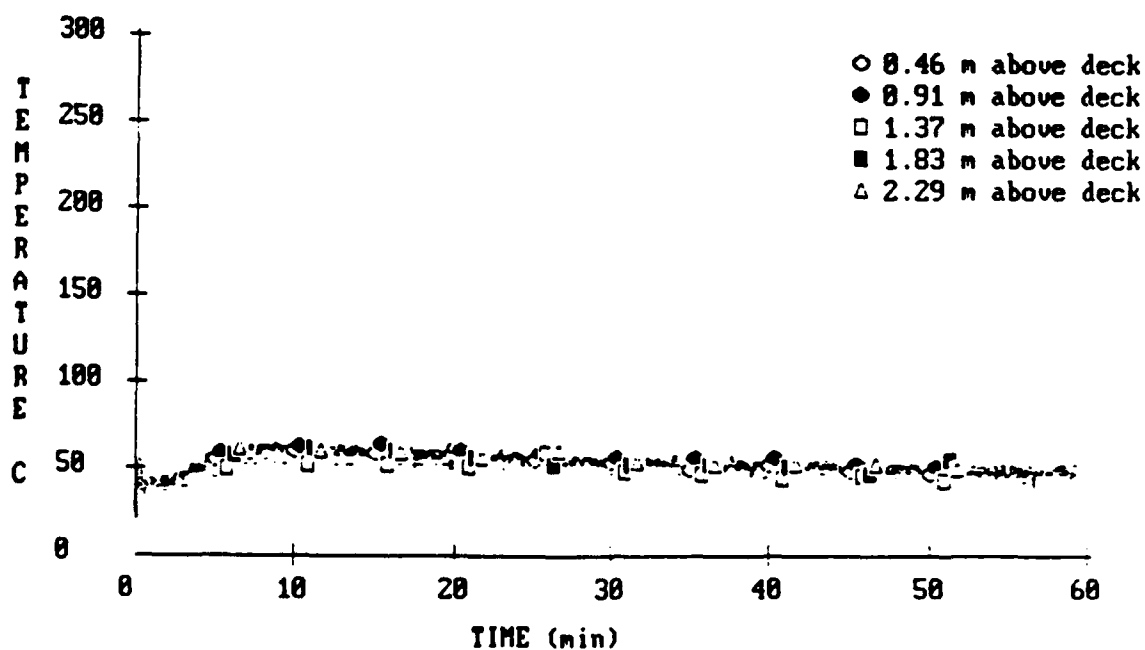


Fig. B-479- Temperature in RICER 2 (2-86-2) during Test # 12

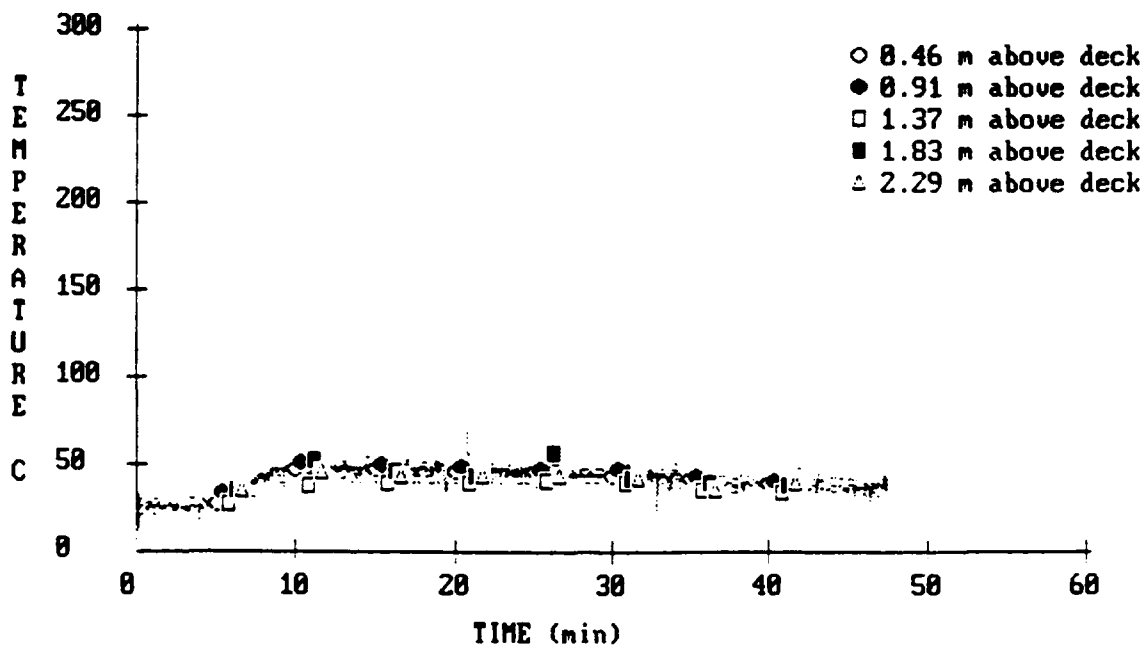


Fig. B-480- Temperature in RICER 2 (2-86-2) during Test # 13

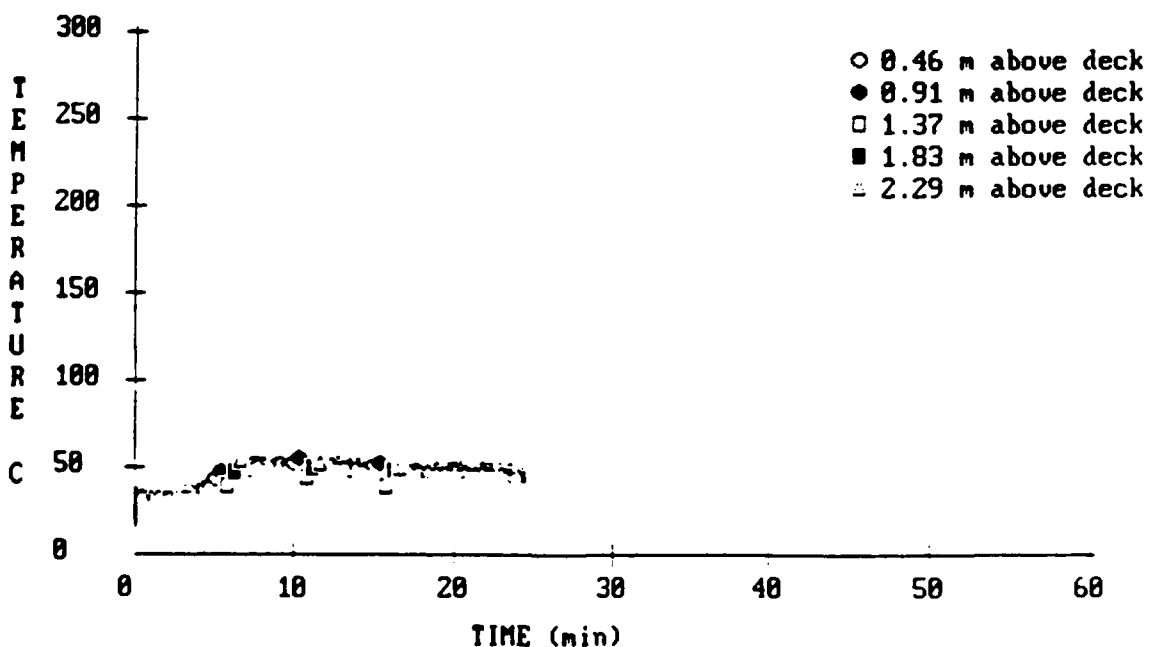


Fig. B-481- Temperature in RICER 2 (2-86-2) during Test # 14

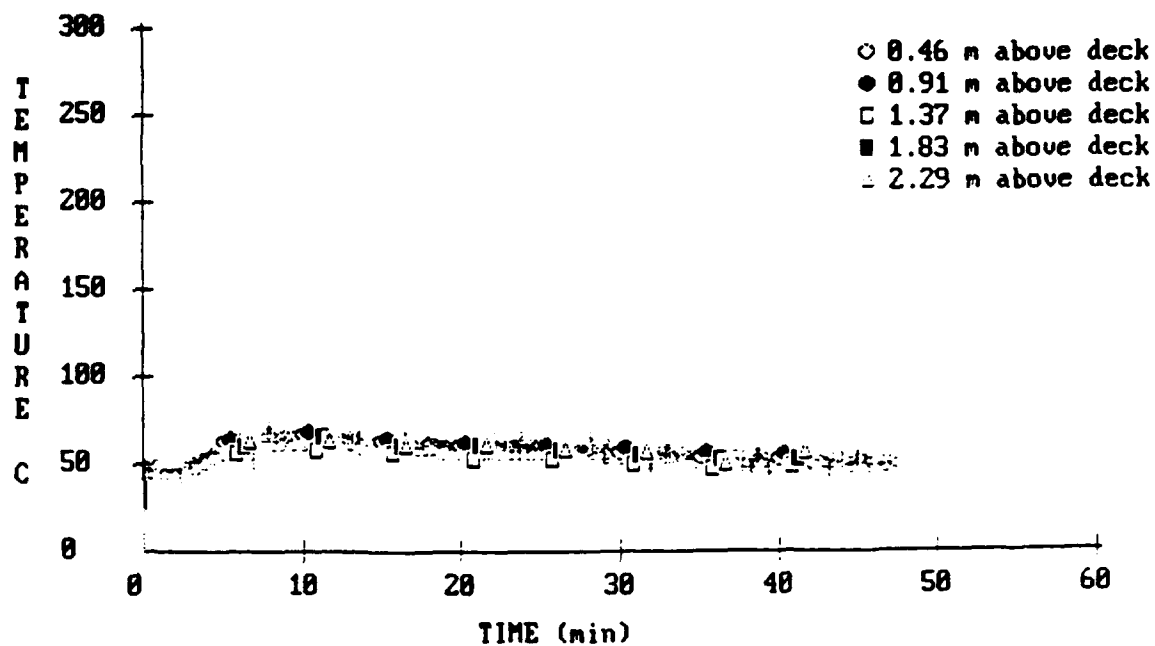


Fig. B-482- Temperature in RICER 2 (2-86-2) during Test # 15

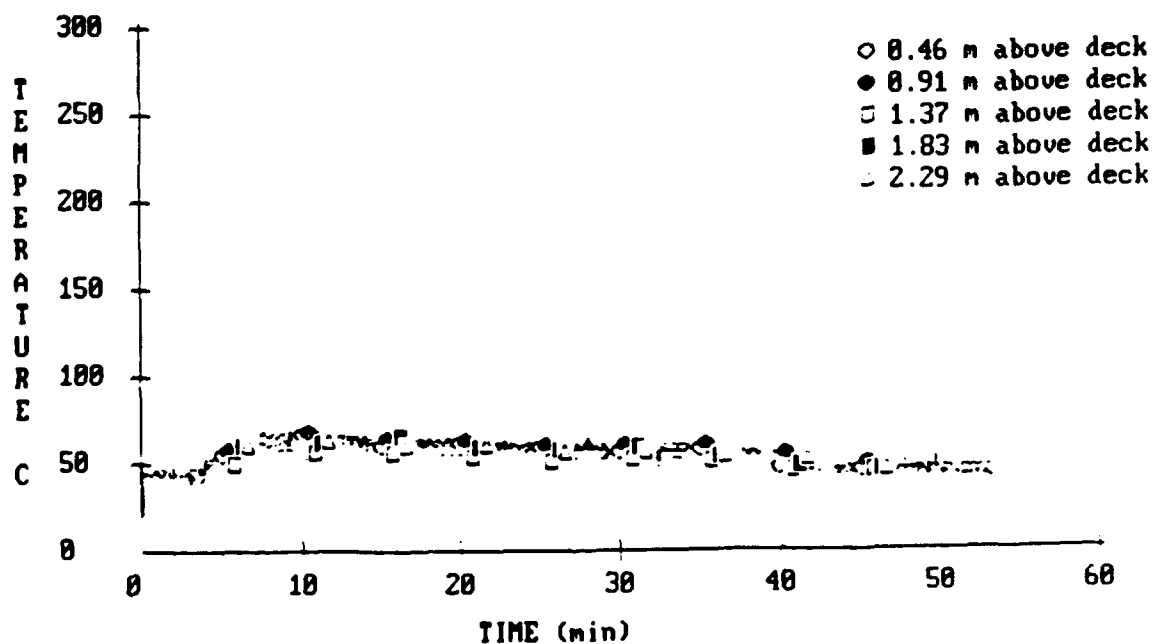


Fig. B-483- Temperature in RICER 2 (2-86-2) during Test # 16

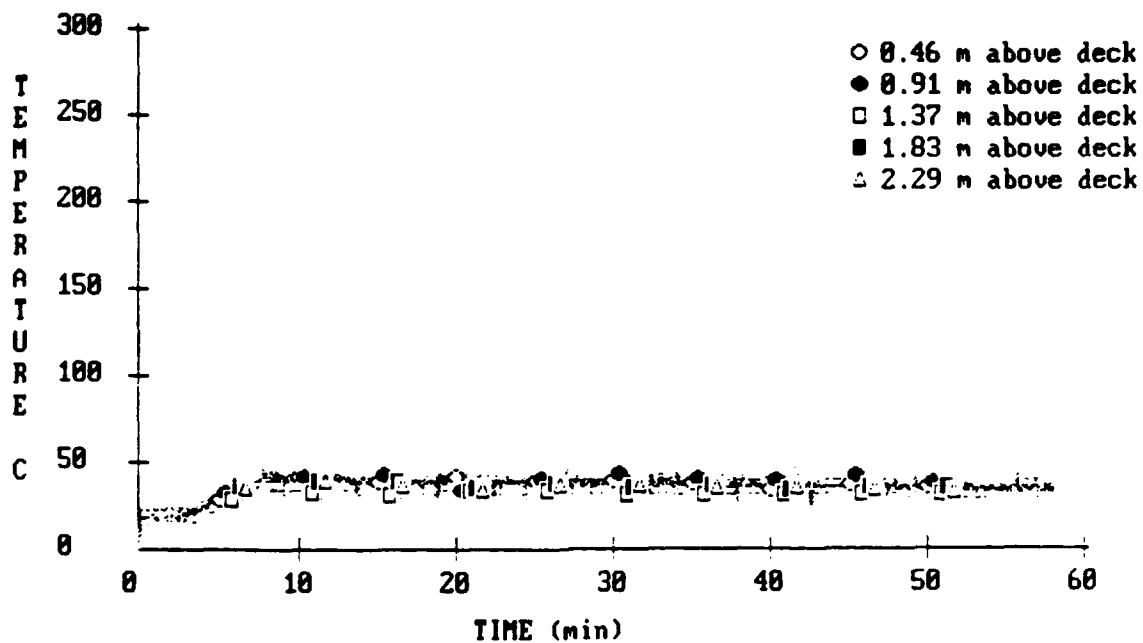


Fig. B-484- Temperature in RICER 2 (2-86-2) during Test # 17

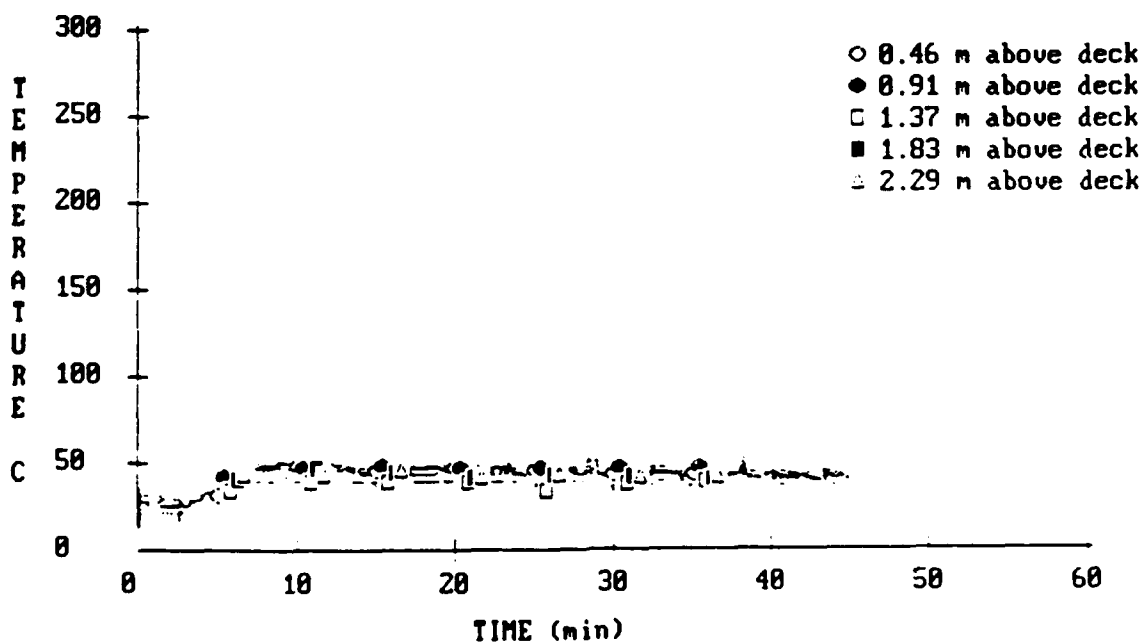


Fig. B-485- Temperature in RICER 2 (2-86-2) during Test # 18



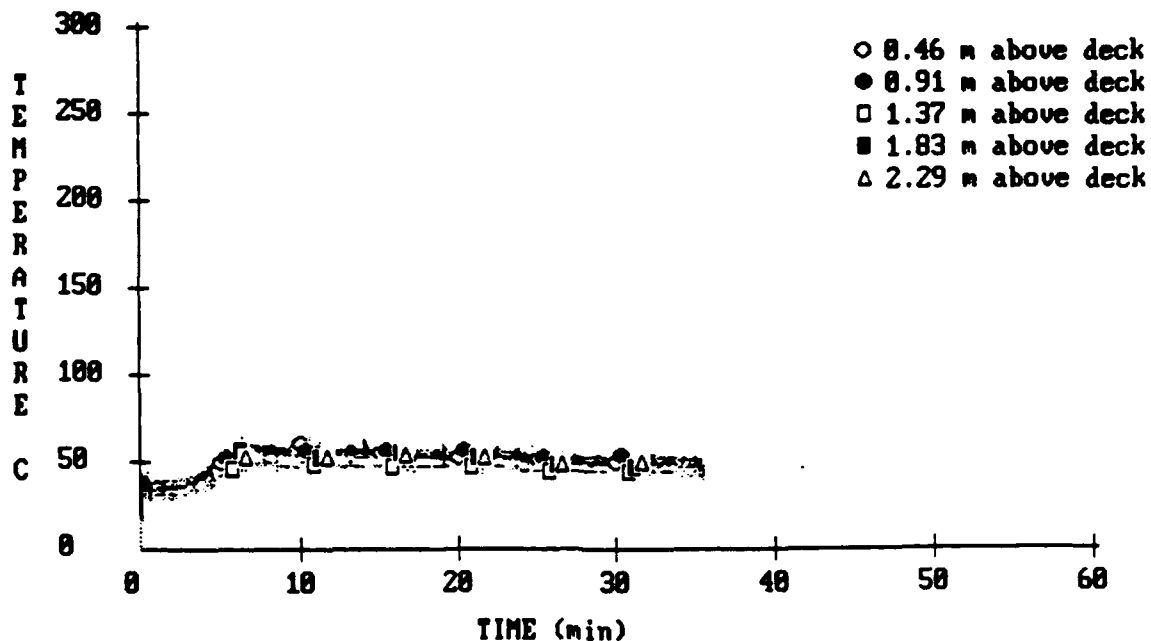


Fig. B-486- Temperature in RICER 2 (2-86-2) during Test # 19

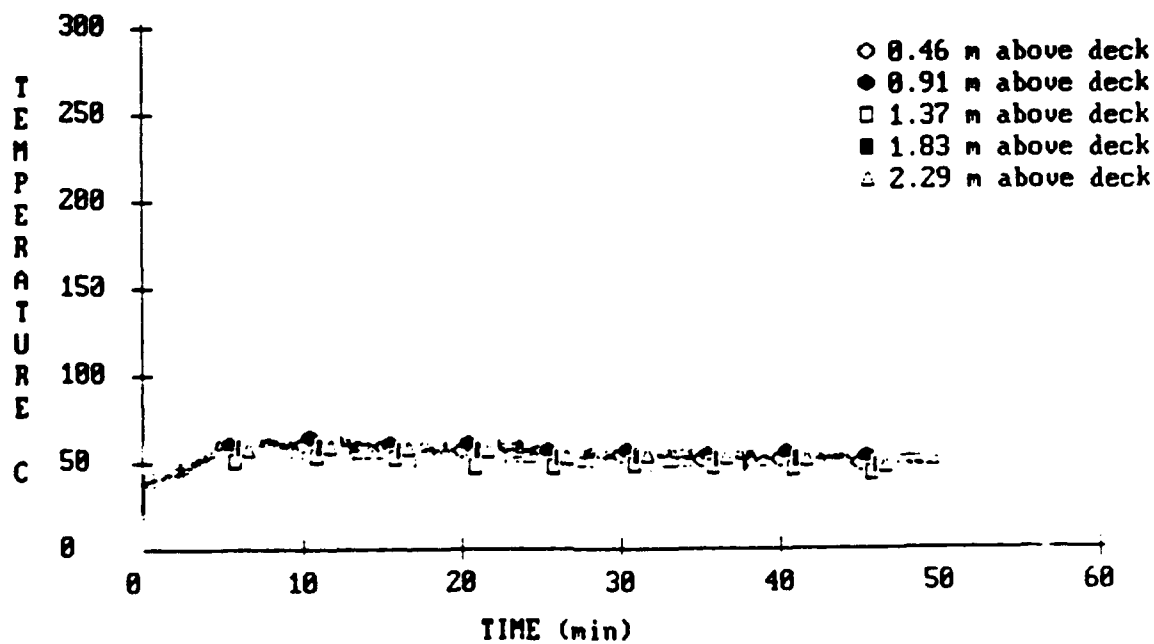


Fig. B-487- Temperature in RICER 2 (2-86-2) during Test # 20

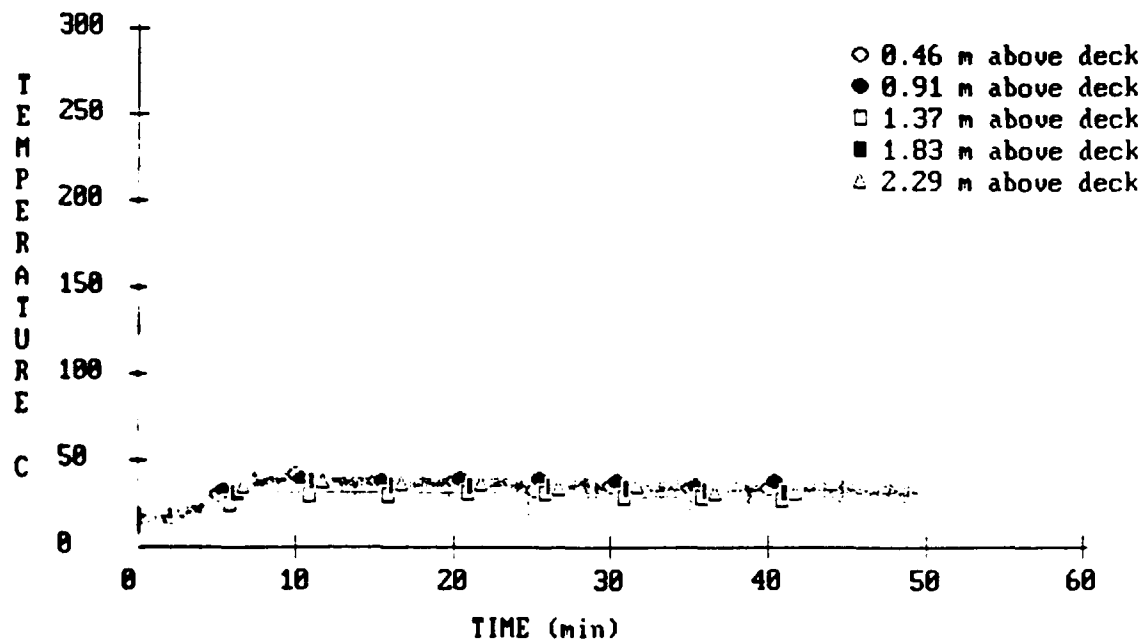


Fig. B-488- Temperature in RICER 2 (2-86-2) during Test # 21

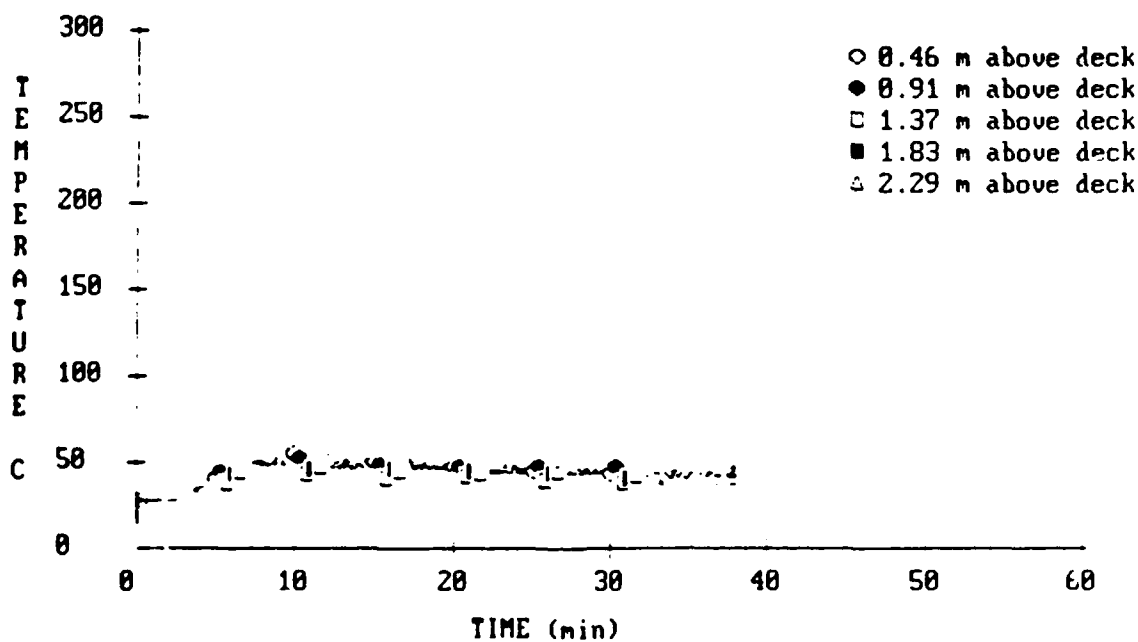


Fig. B-489- Temperature in RICER 2 (2-86-2) during Test # 22

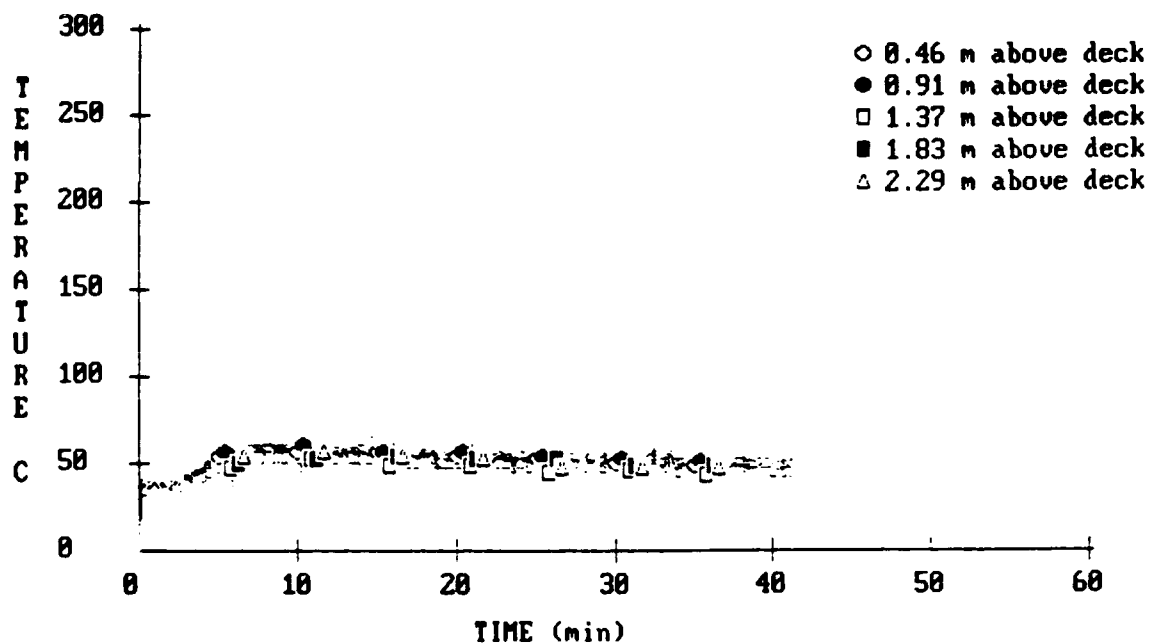


Fig. B-490- Temperature in RICER 2 (2-86-2) during Test # 23

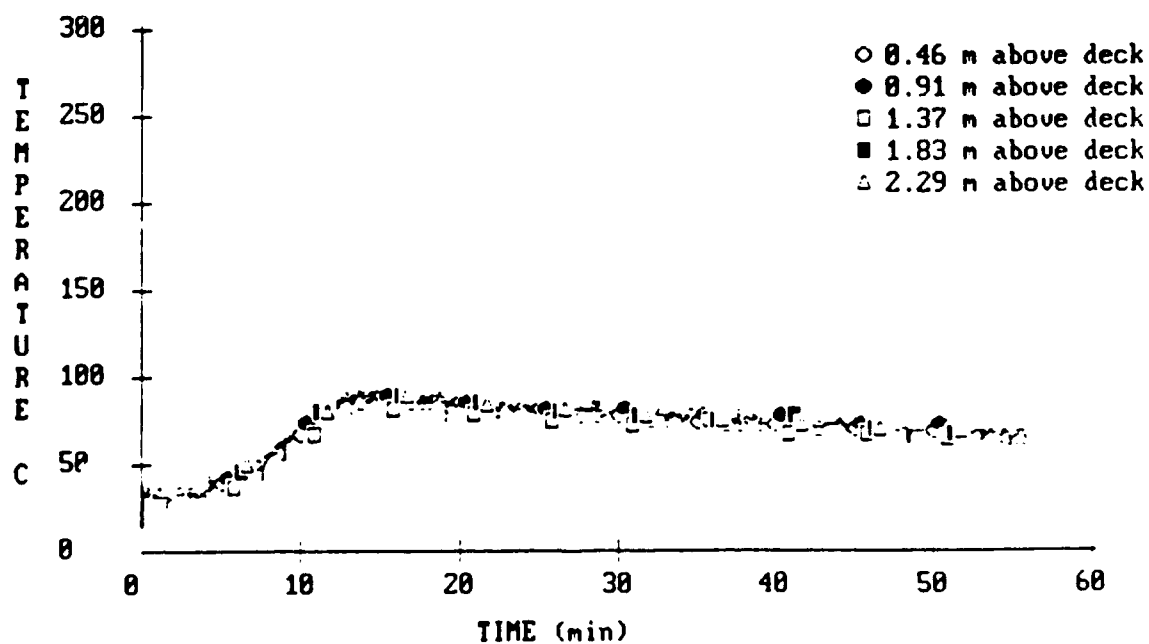


Fig. B-491- Temperature in RICER 2 (2-86-2) during Test # 24

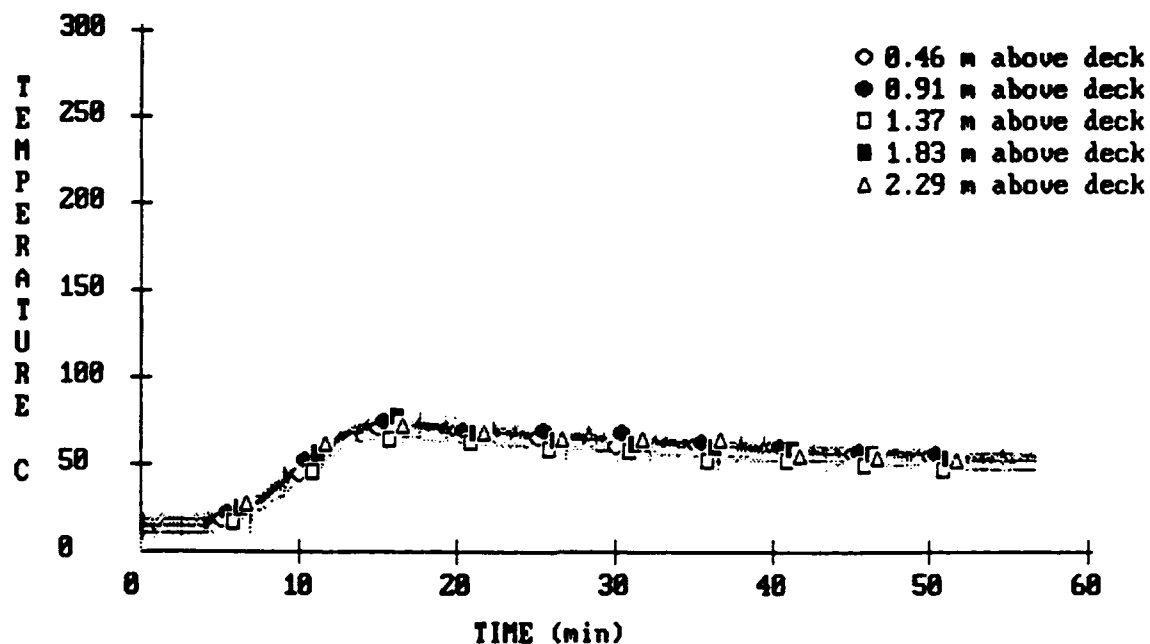


Fig. B-492- Temperature in RICER 2 (2-86-2) during Test # 25

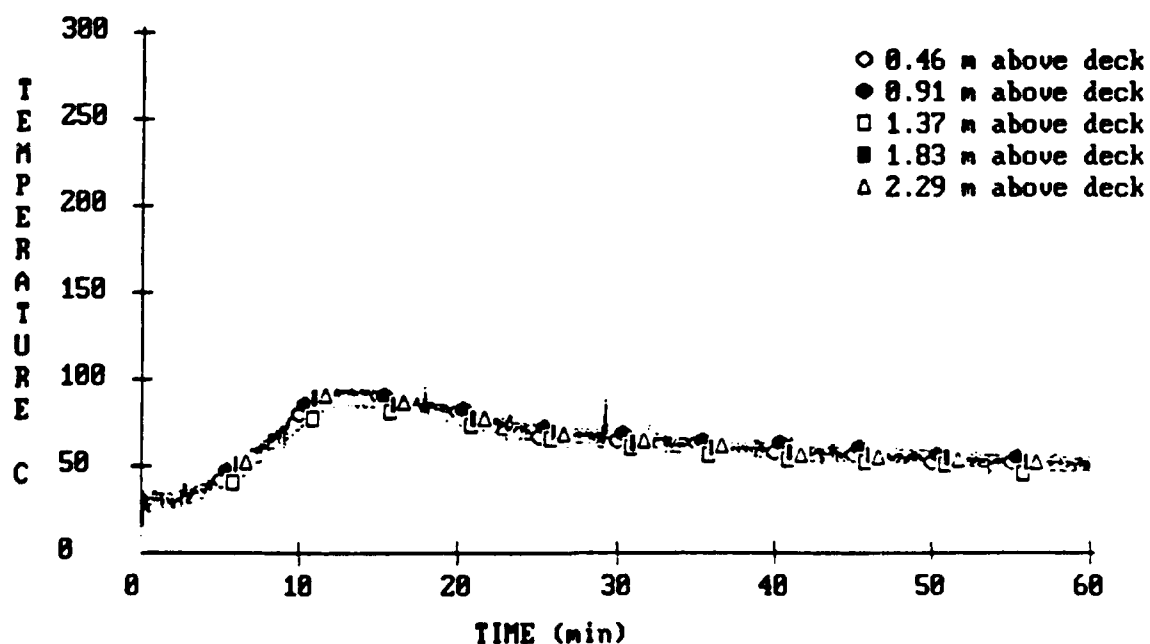


Fig. B-493- Temperature in RICER 2 (2-86-2) during Test # 26

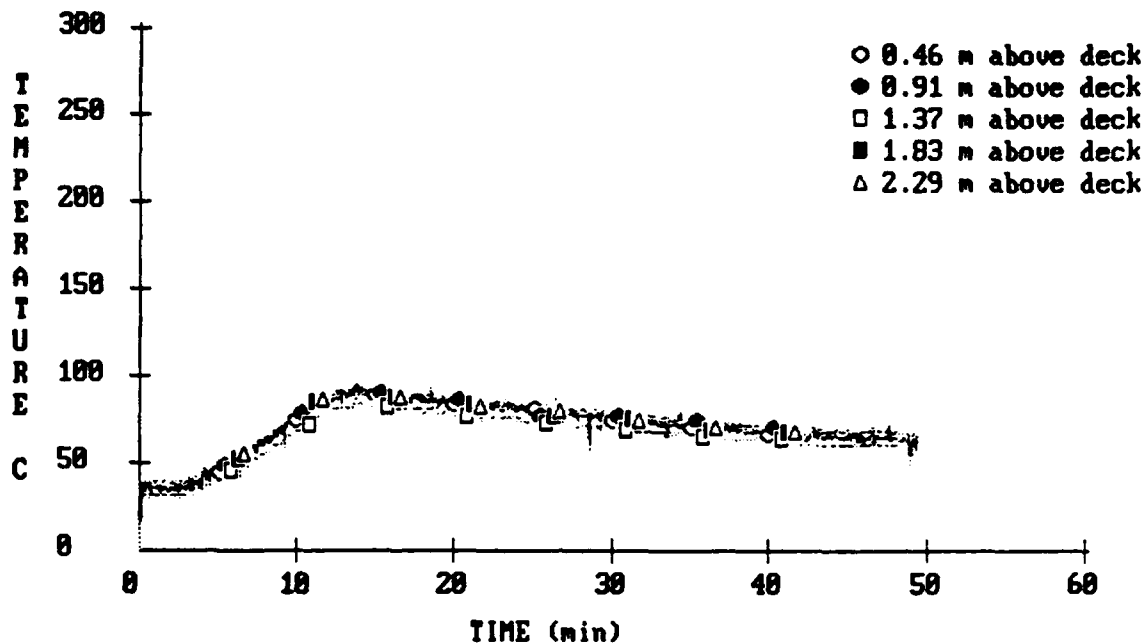


Fig. B-494- Temperature in RICER 2 (2-86-2) during Test # 27

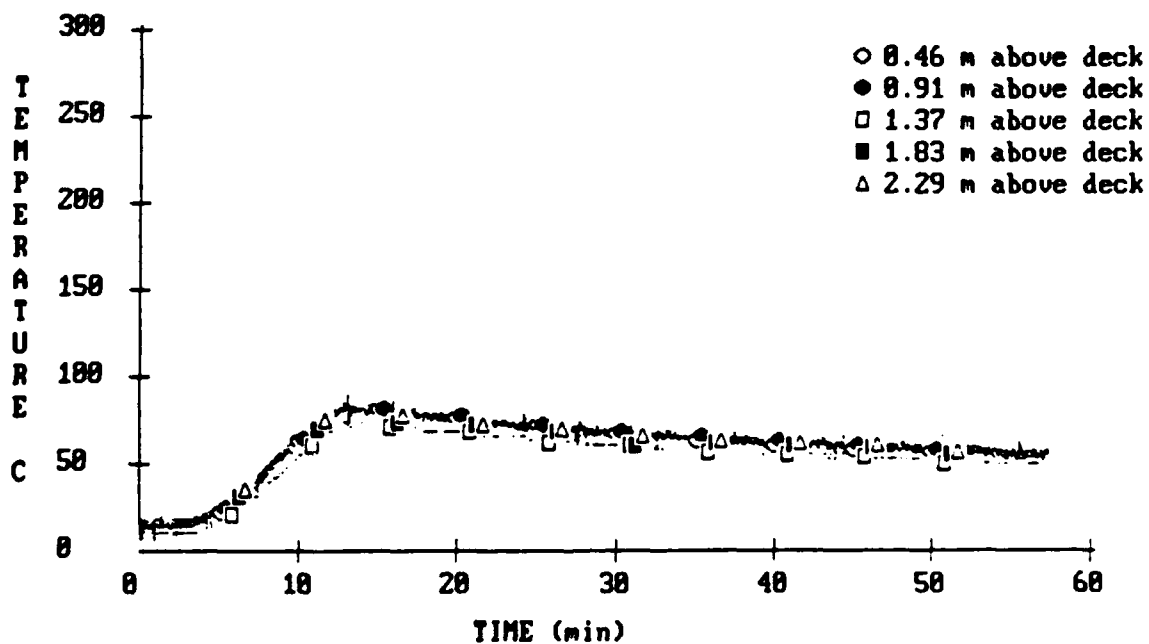


Fig. B-495- Temperature in RICER 2 (2-86-2) during Test # 28

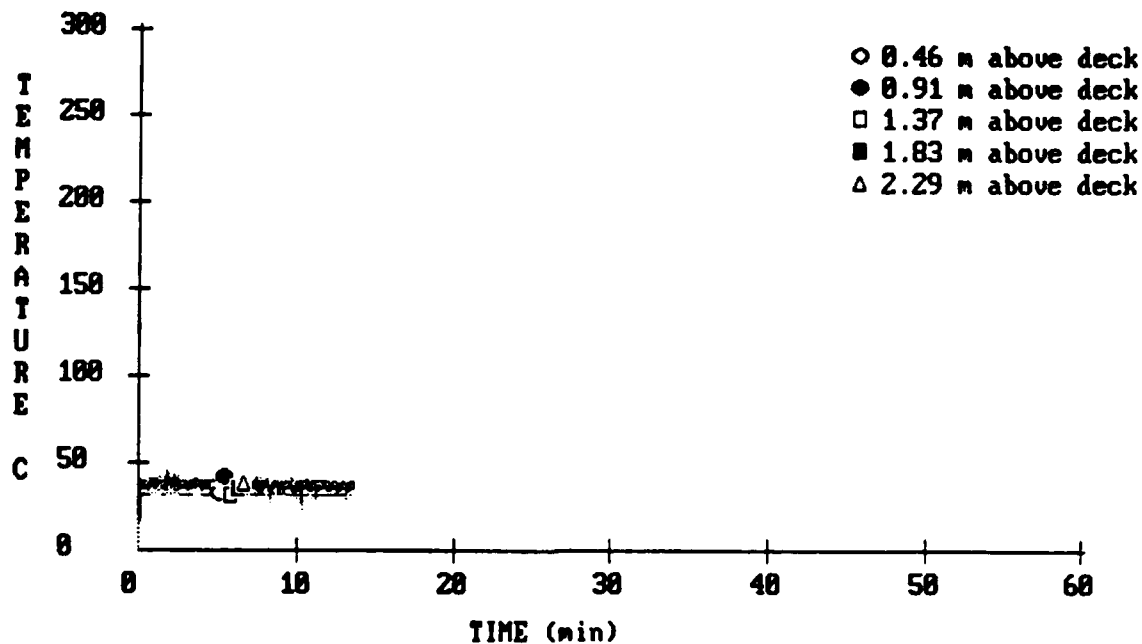


Fig. B-496- Temperature in RICER 2 (2-86-2) during Test # 29

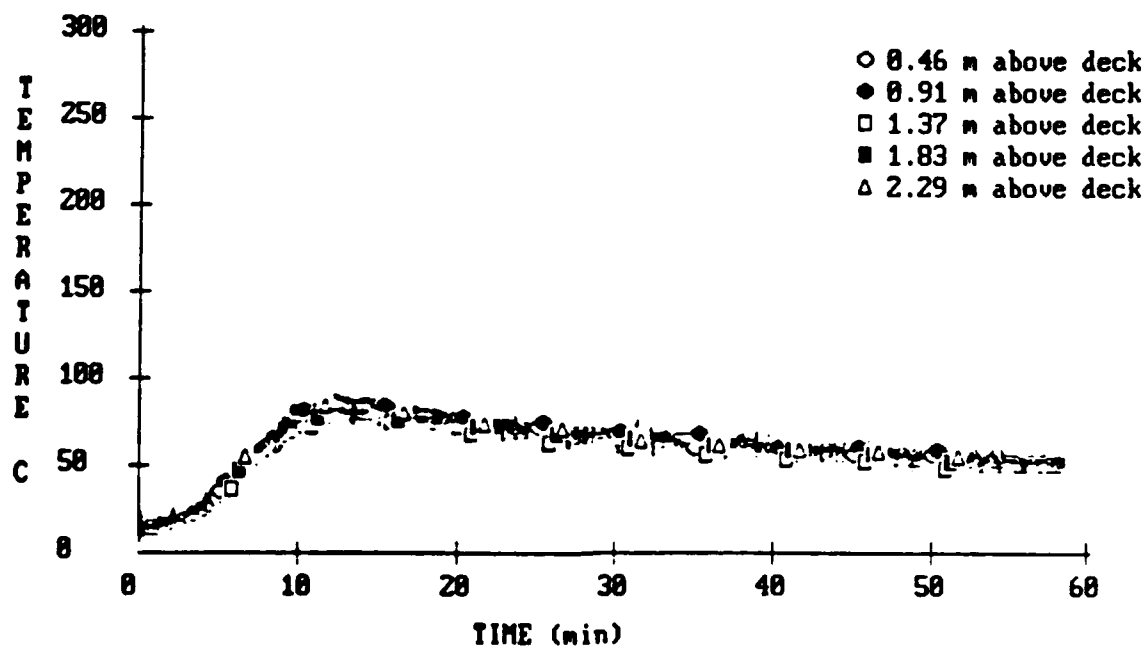


Fig. B-497- Temperature in RICER 2 (2-86-2) during Test # 30

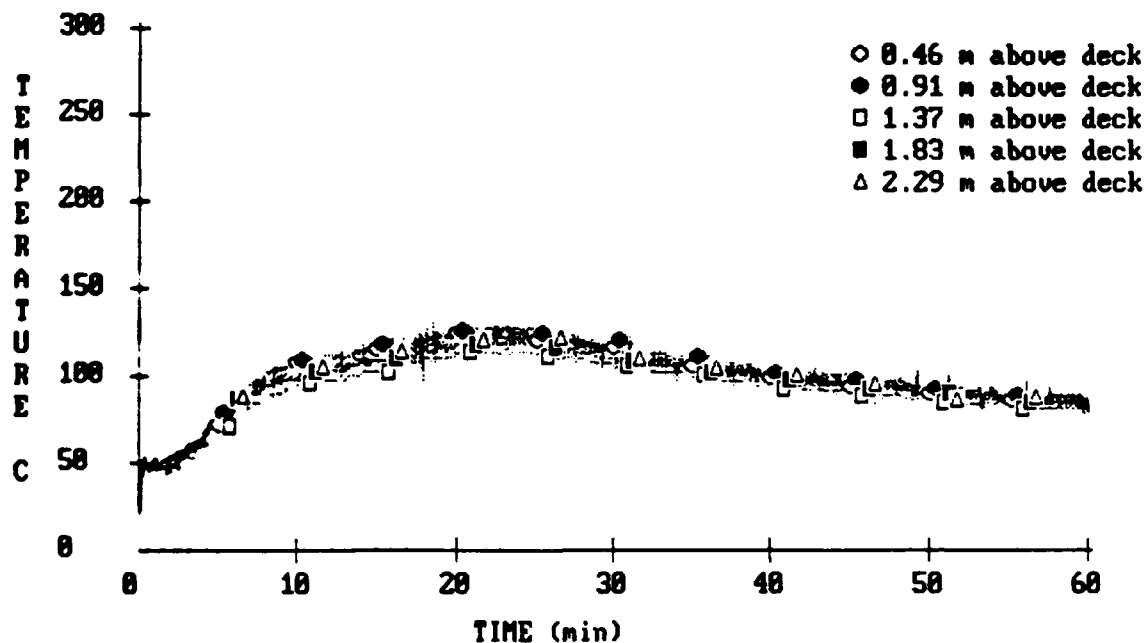


Fig. B-498- Temperature in RICER 2 (2-86-2) during Test # 31

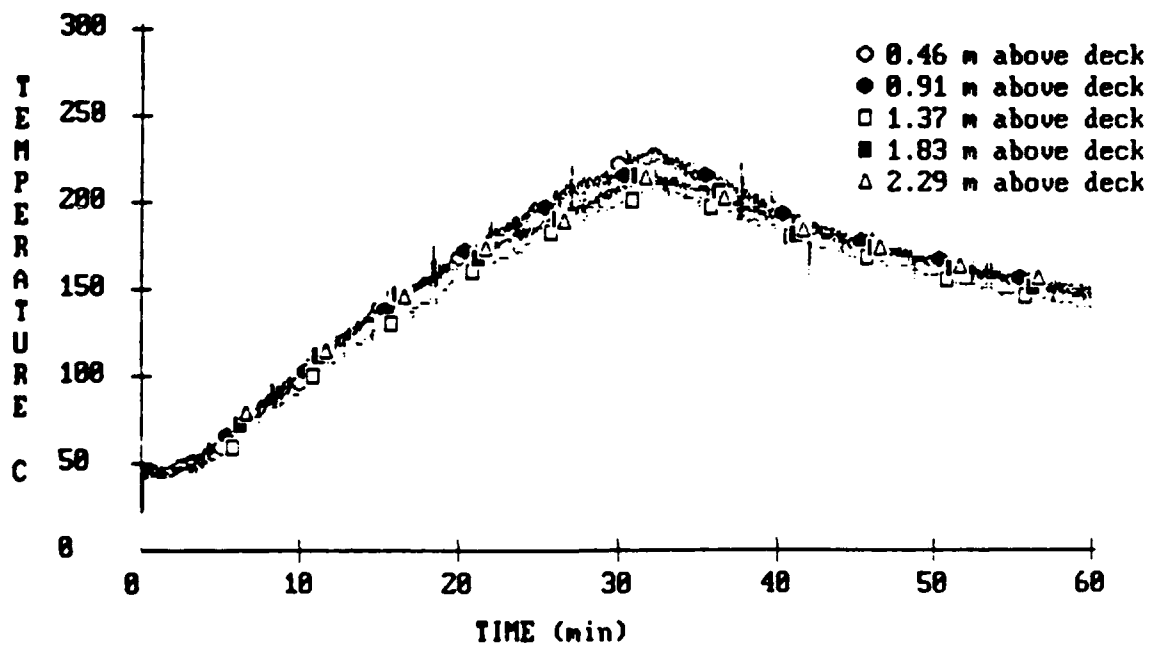


Fig. B-499- Temperature in RICER 2 (2-86-2) during Test # 32

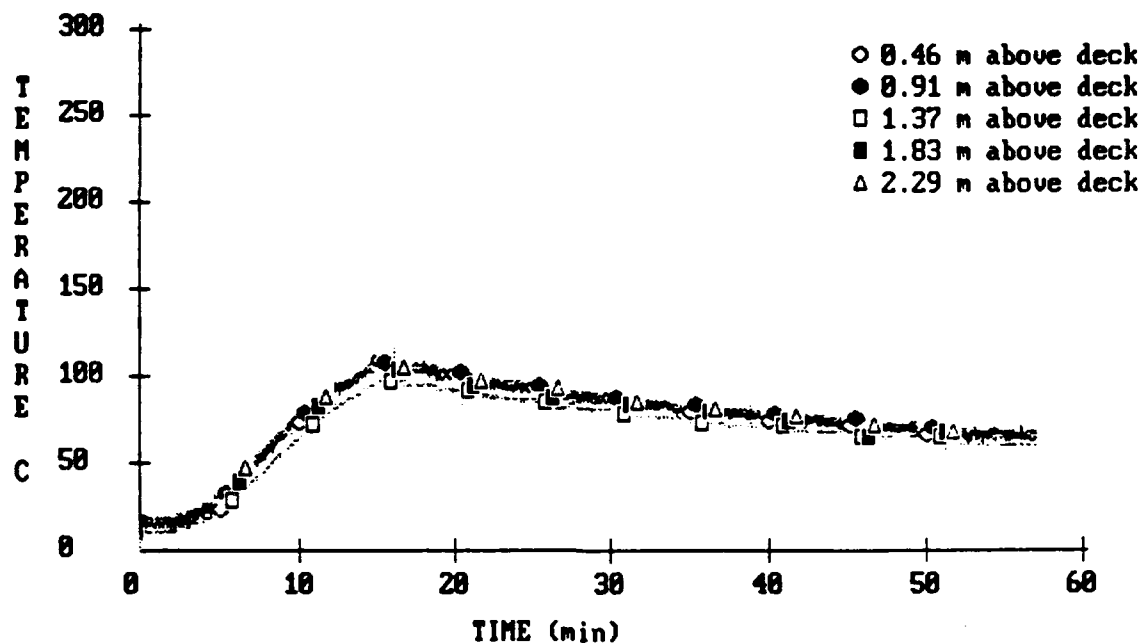


Fig. B-500- Temperature in RICER 2 (2-86-2) during Test # 33

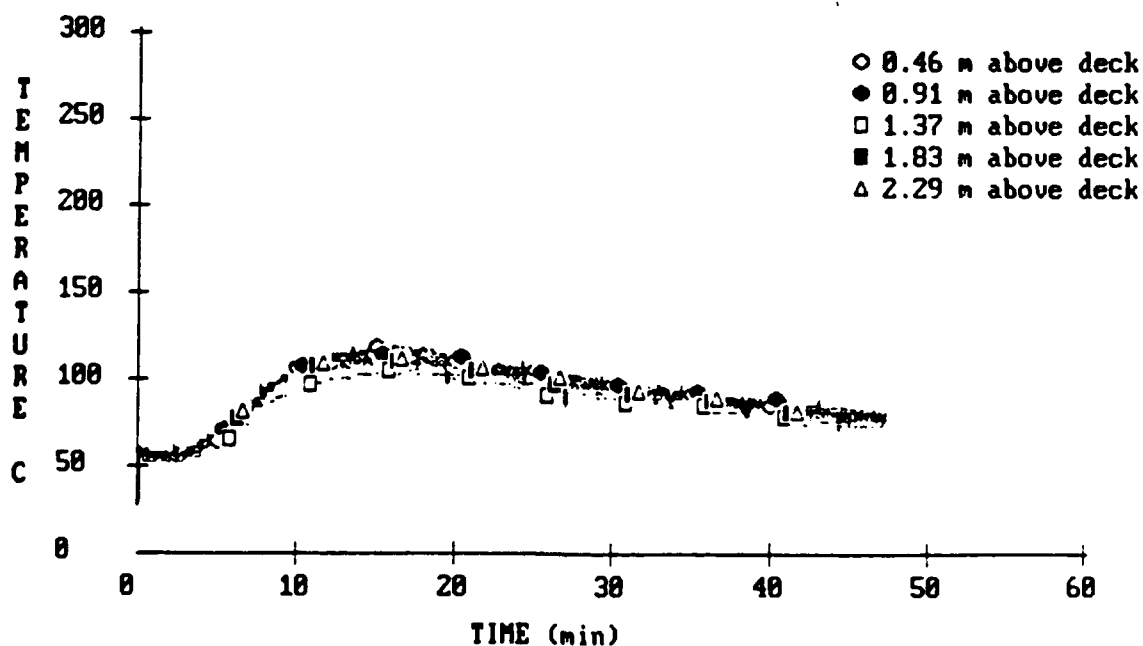


Fig. B-501- Temperature in RICER 2 (2-86-2) during Test # 34



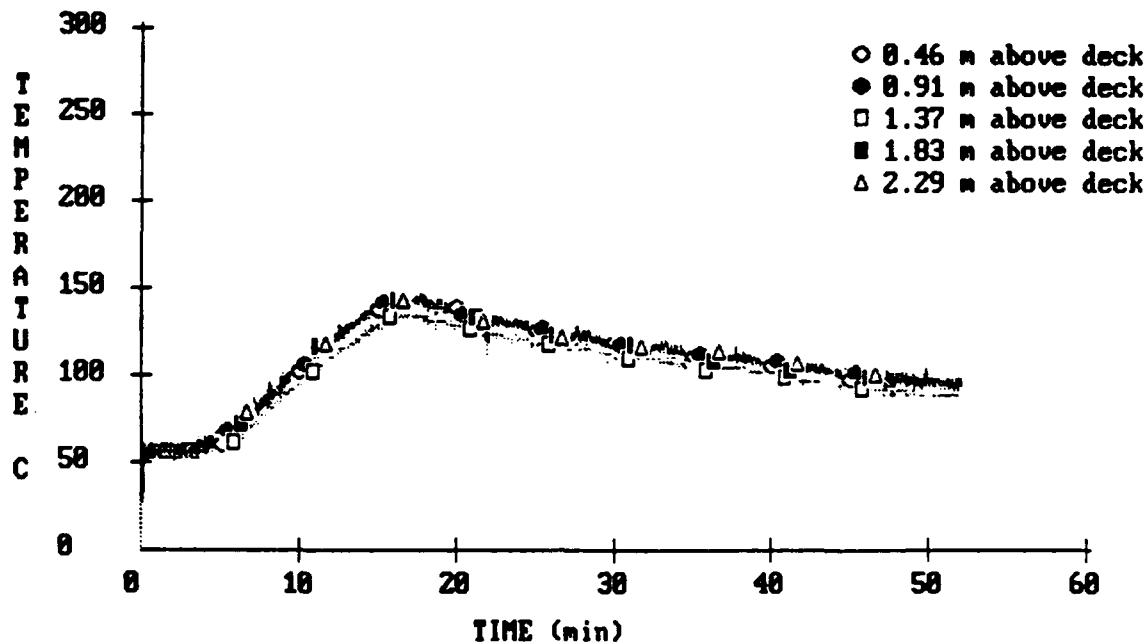


Fig. B-502- Temperature in RICER 2 (2-86-2) during Test # 35

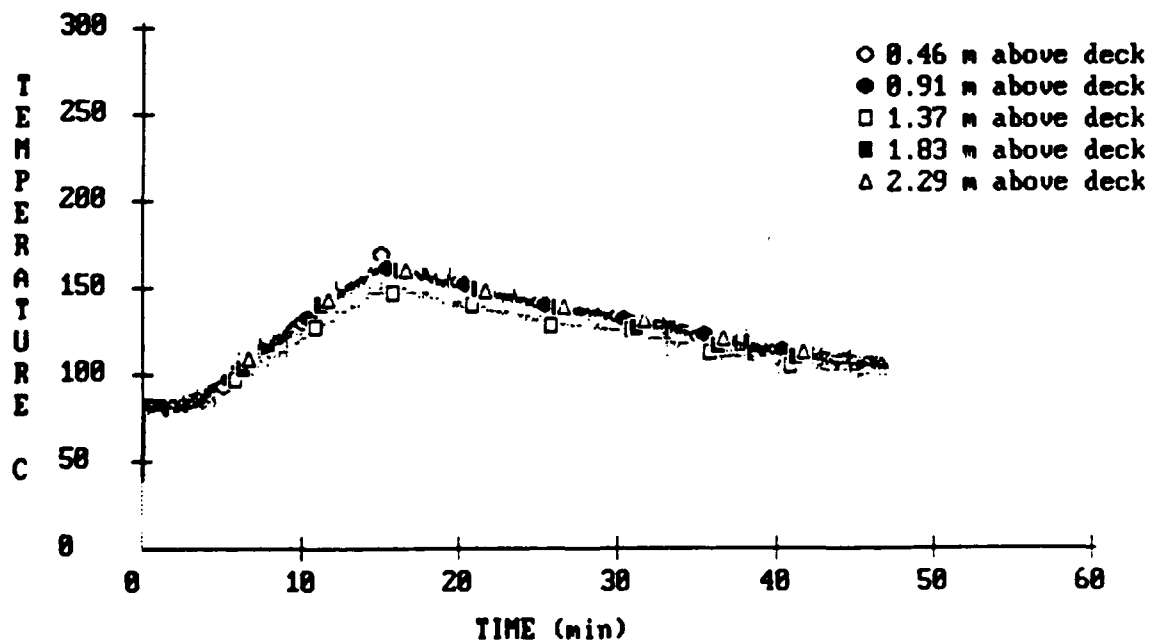


Fig. B-503- Temperature in RICER 2 (2-86-2) during Test # 36

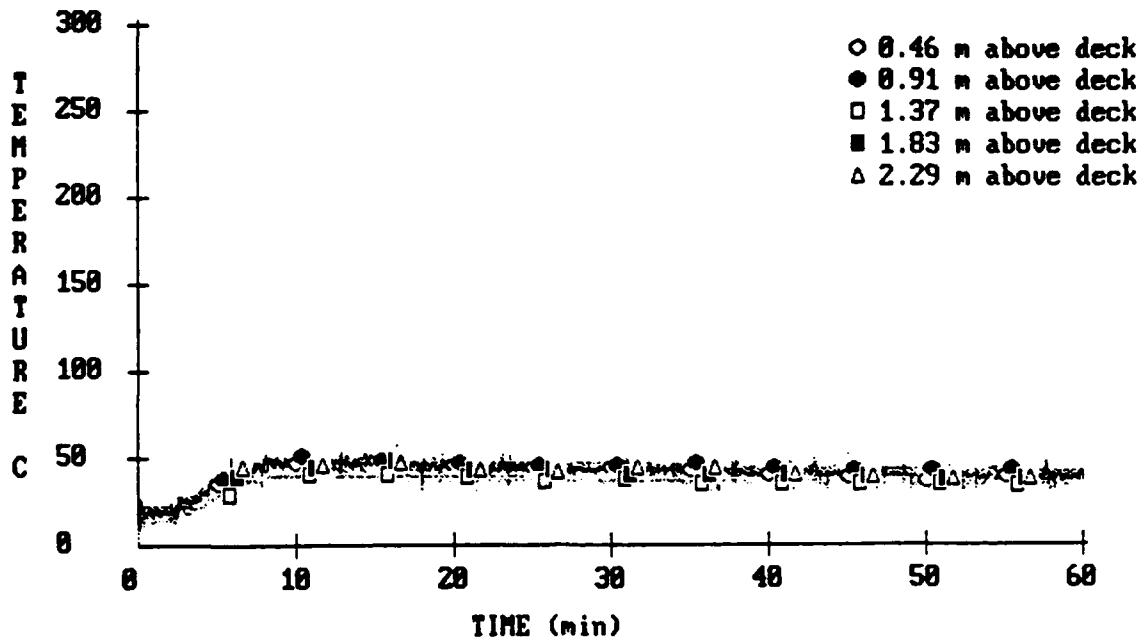


Fig. B-504- Temperature in RICER 2 (2-86-2) during Test # 37

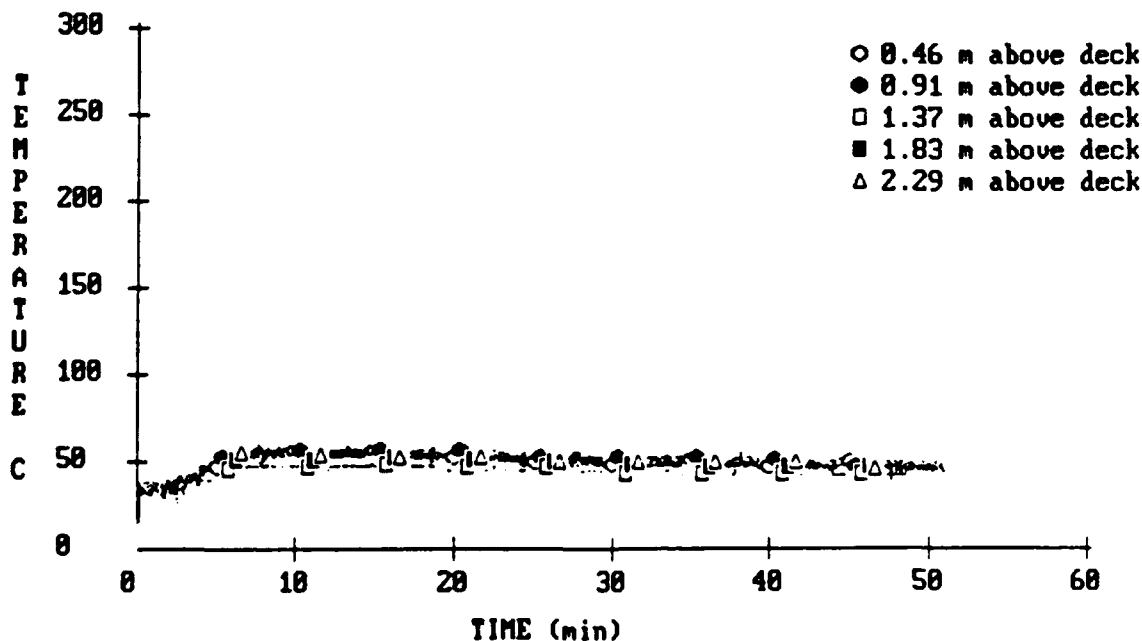


Fig. B-505- Temperature in RICER 2 (2-86-2) during Test # 38

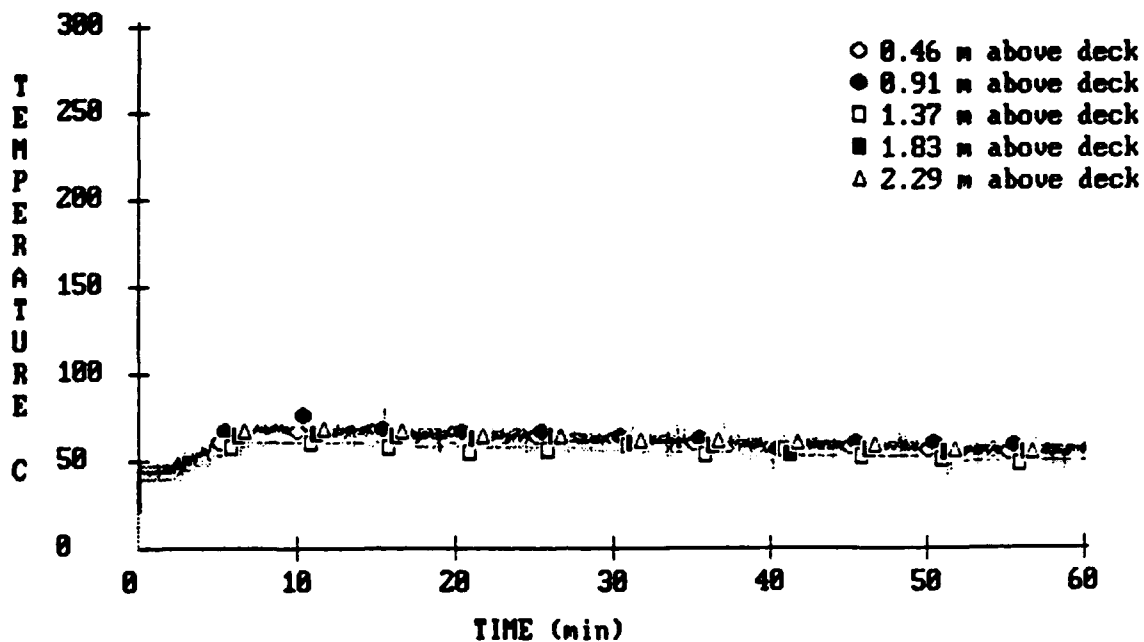


Fig. B-506- Temperature in RICER 2 (2-86-2) during Test # 39

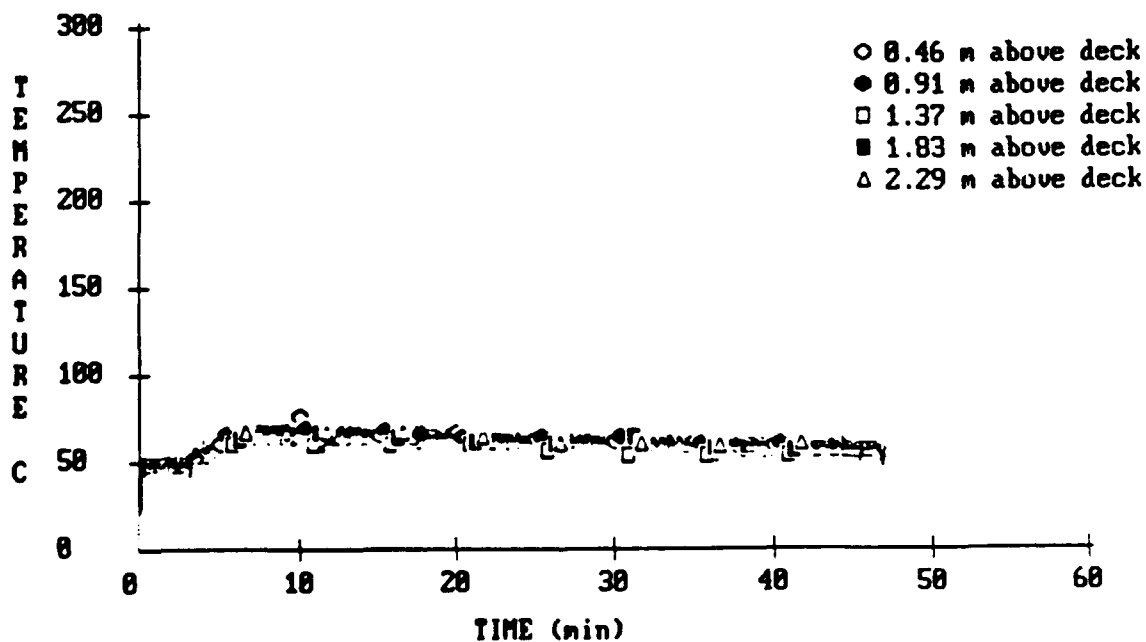


Fig. B-507- Temperature in RICER 2 (2-86-2) during Test # 40

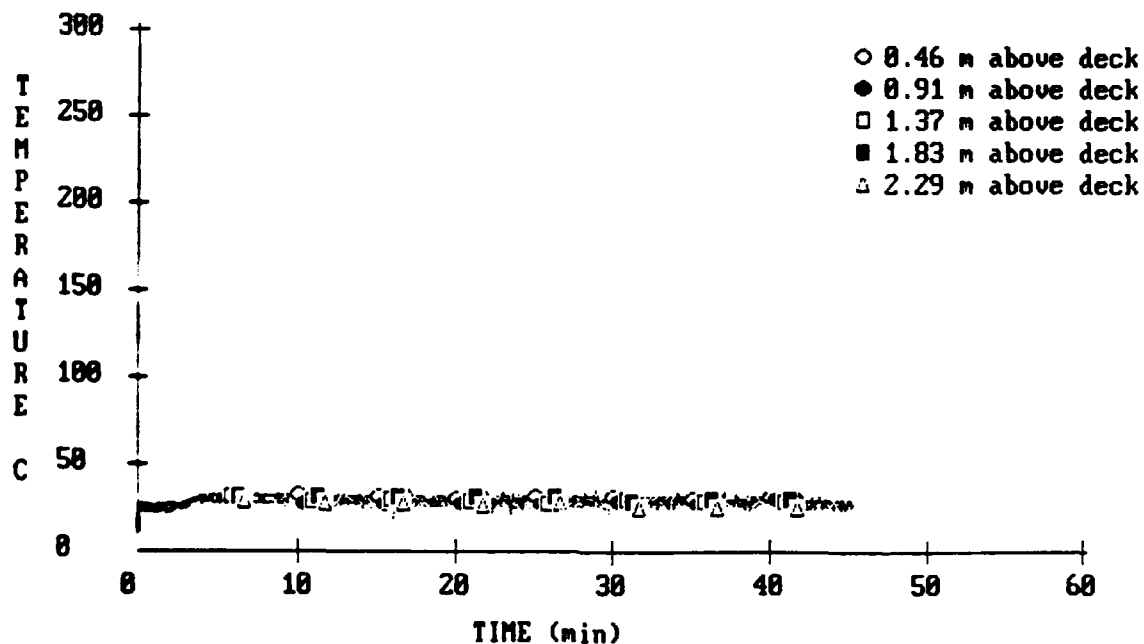


Fig. B-508- Temperature in RICER 1 (2-79-2) during Test # 2

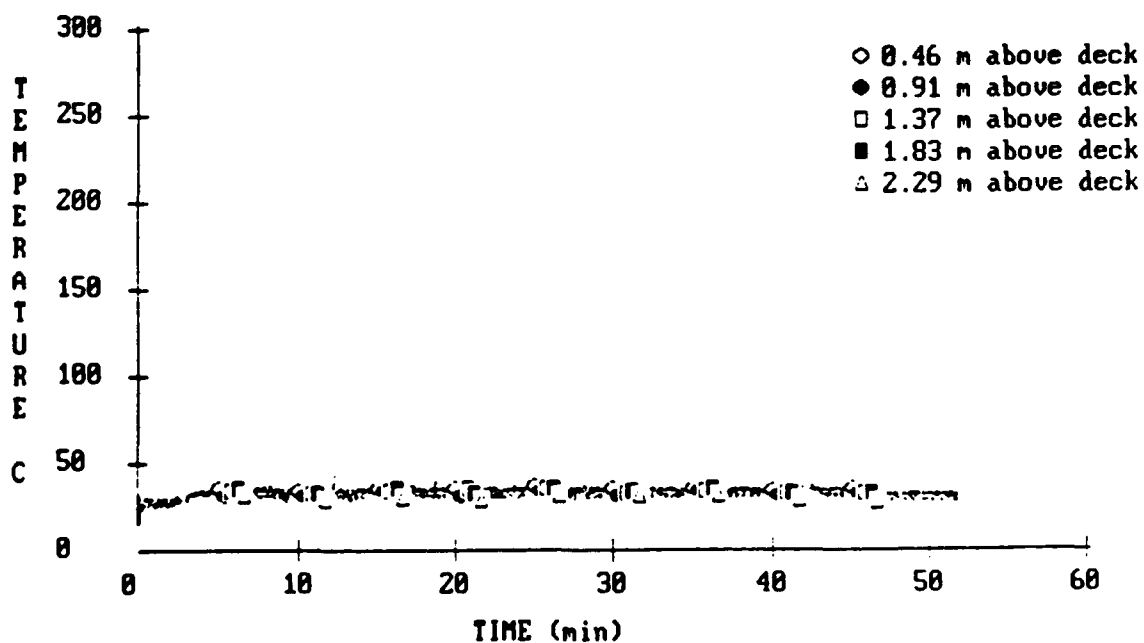


Fig. B-509- Temperature in RICER 1 (2-79-2) during Test # 3

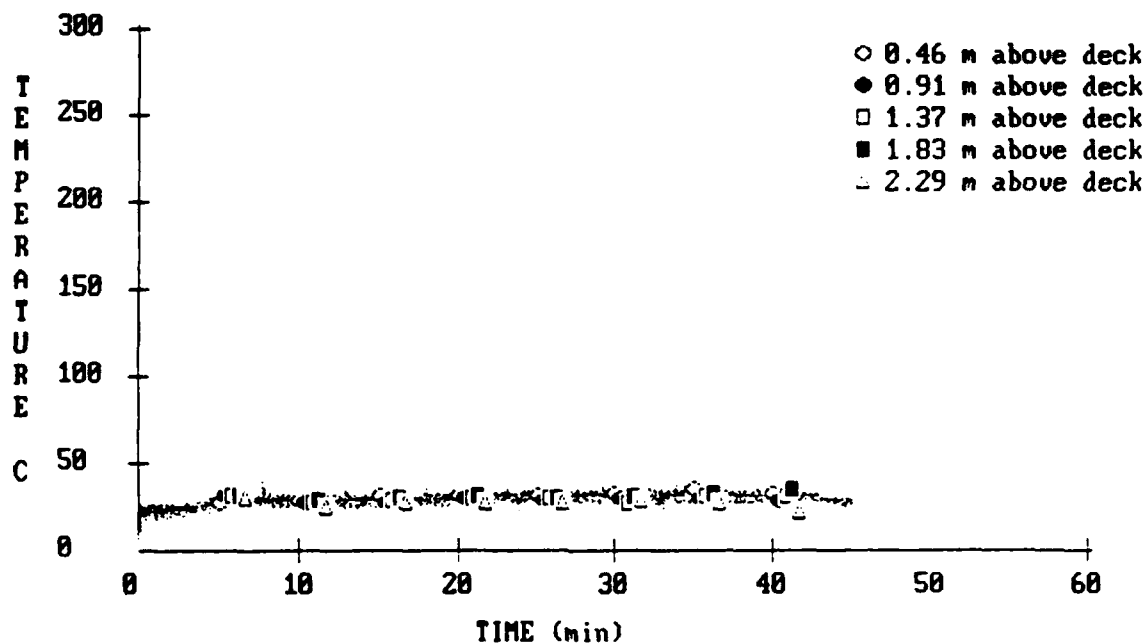


Fig. B-510- Temperature in RICER 1 (2-79-2) during Test # 4

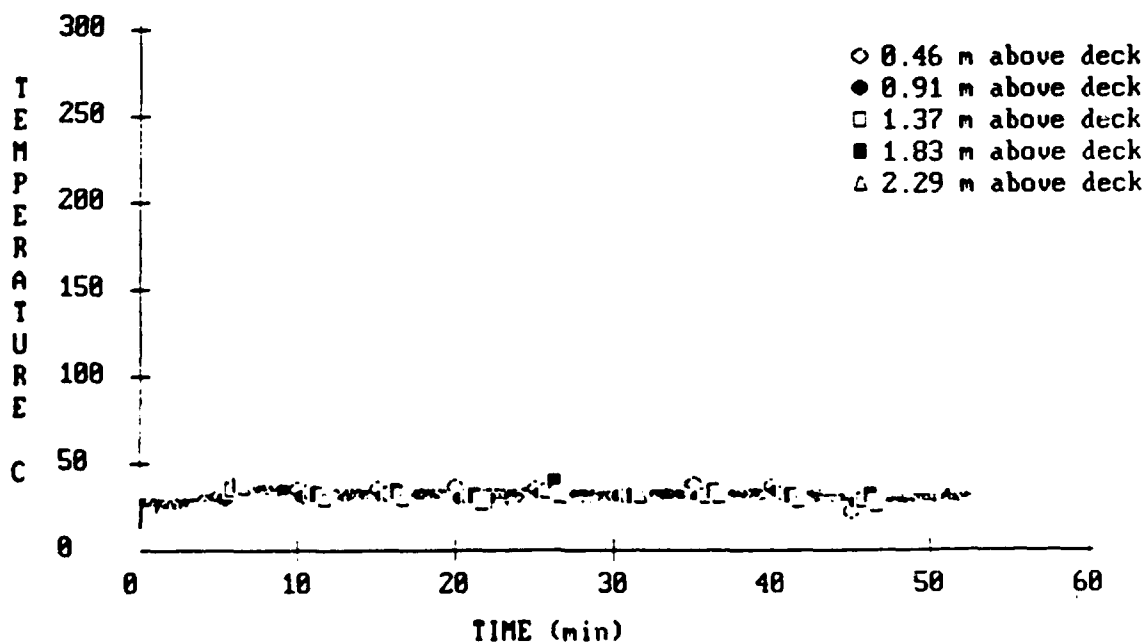


Fig. B-511- Temperature in RICER 1 (2-79-2) during Test # 5

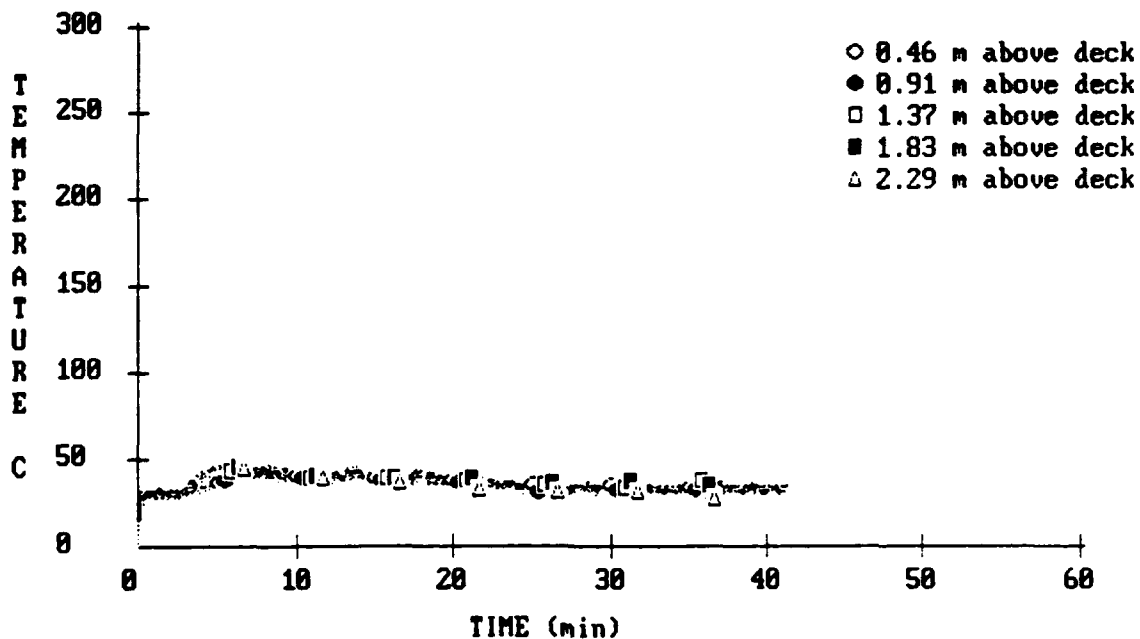


Fig. B-512- Temperature in RICER 1 (2-79-2) during Test # 6

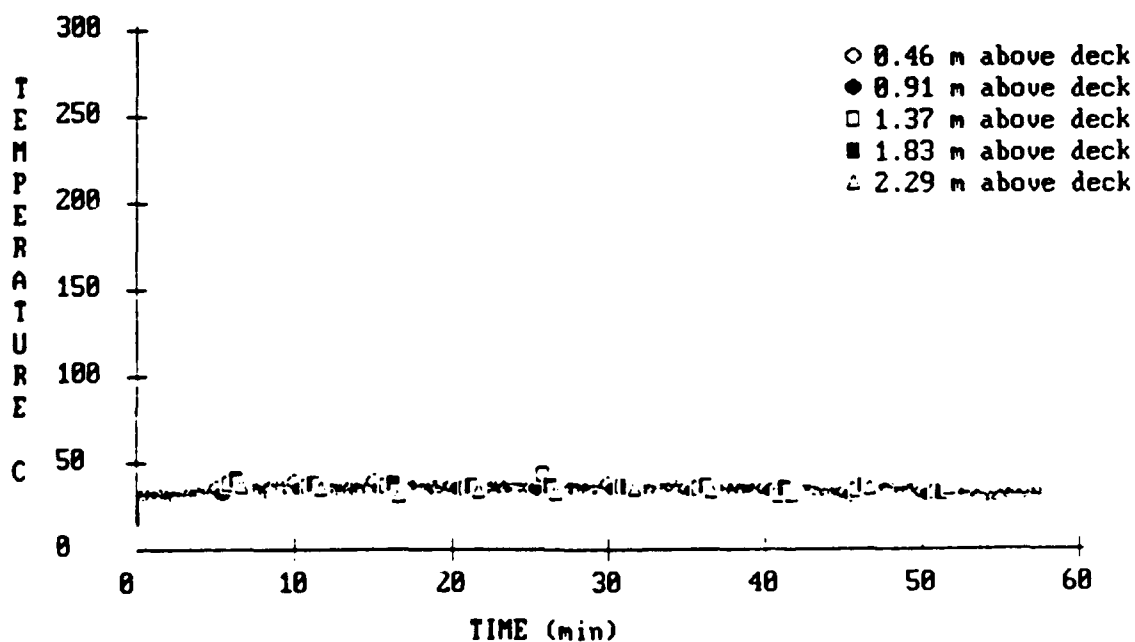


Fig. B-513- Temperature in RICER 1 (2-79-2) during Test # 7

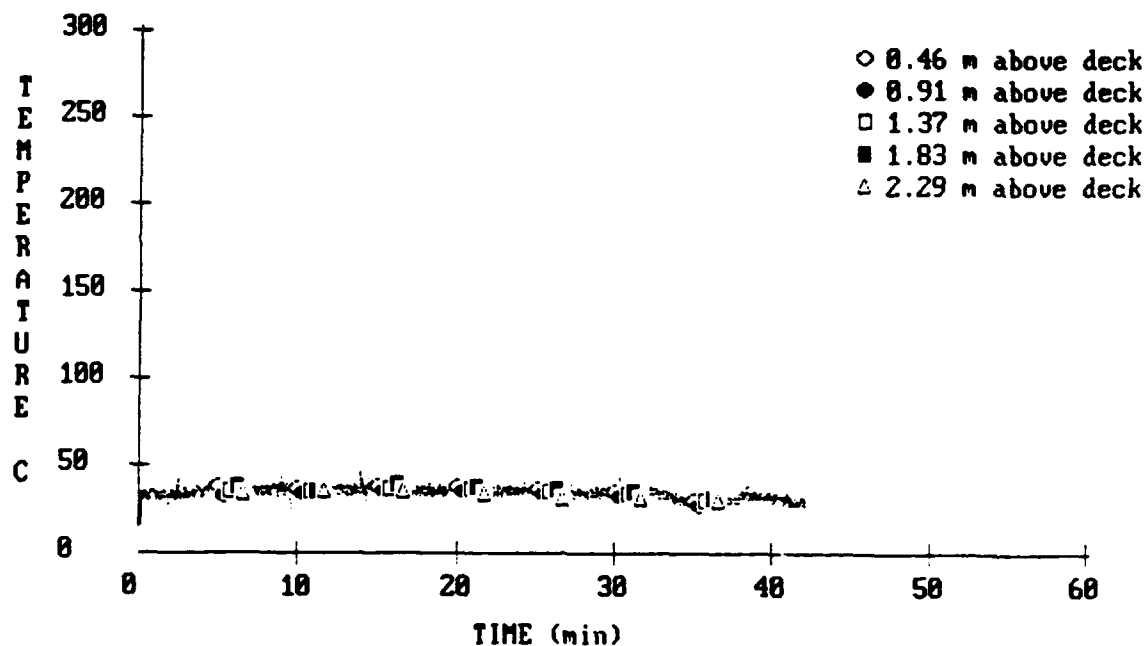


Fig. B-514- Temperature in RICER 1 (2-79-2) during Test # 8

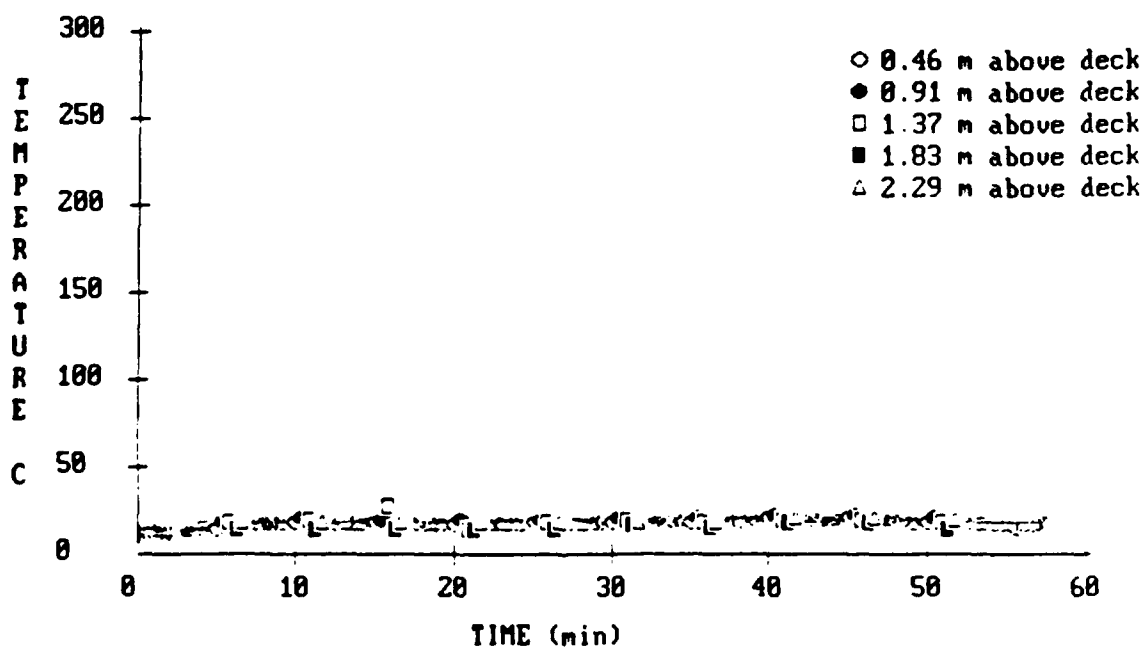


Fig. B-515- Temperature in RICER 1 (2-79-2) during Test # 9

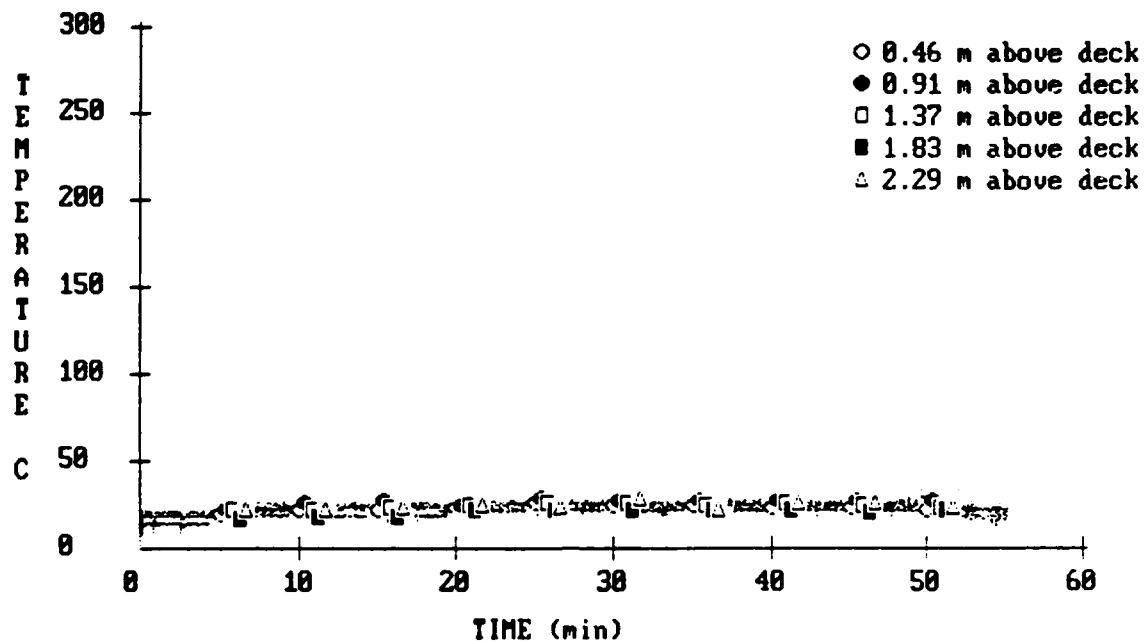


Fig. B-516- Temperature in RICER 1 (2-79-2) during Test # 10

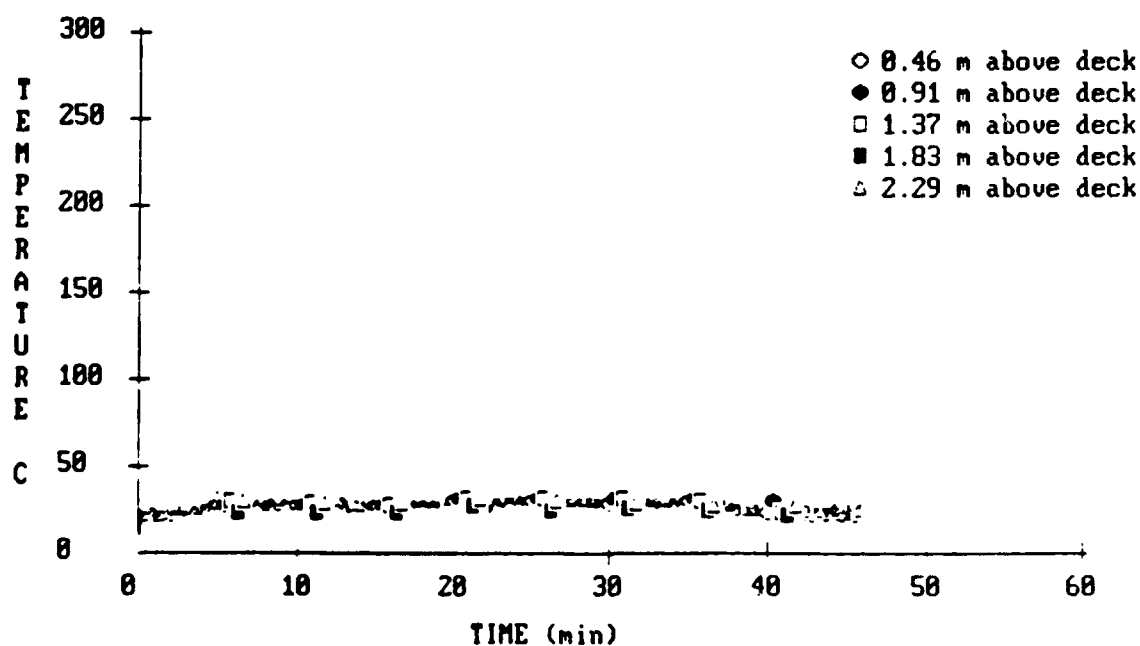


Fig. B-517- Temperature in RICER 1 (2-79-2) during Test # 11



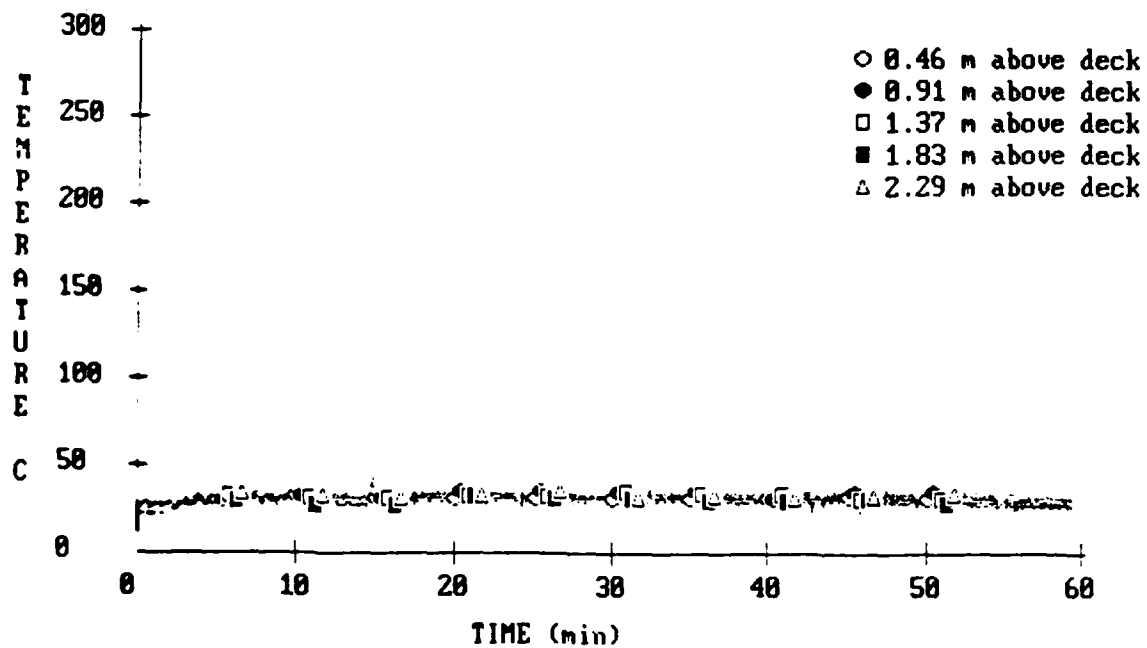


Fig. B-518- Temperature in RICER 1 (2-79-2) during Test # 12

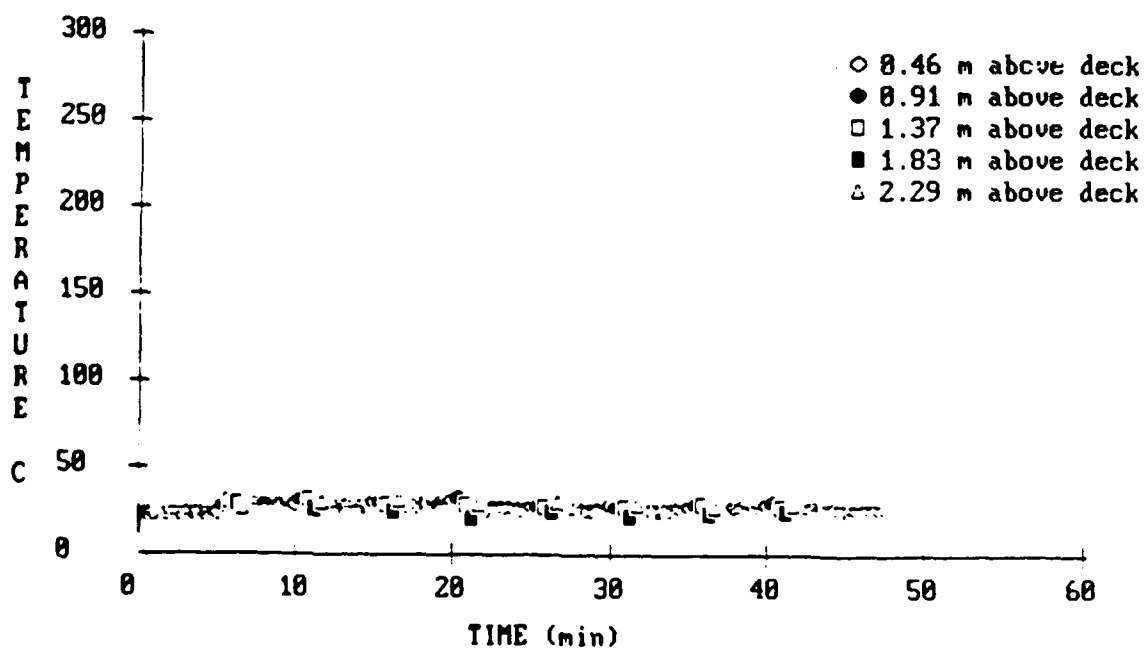


Fig. B-519- Temperature in RICER 1 (2-79-2) during Test # 13

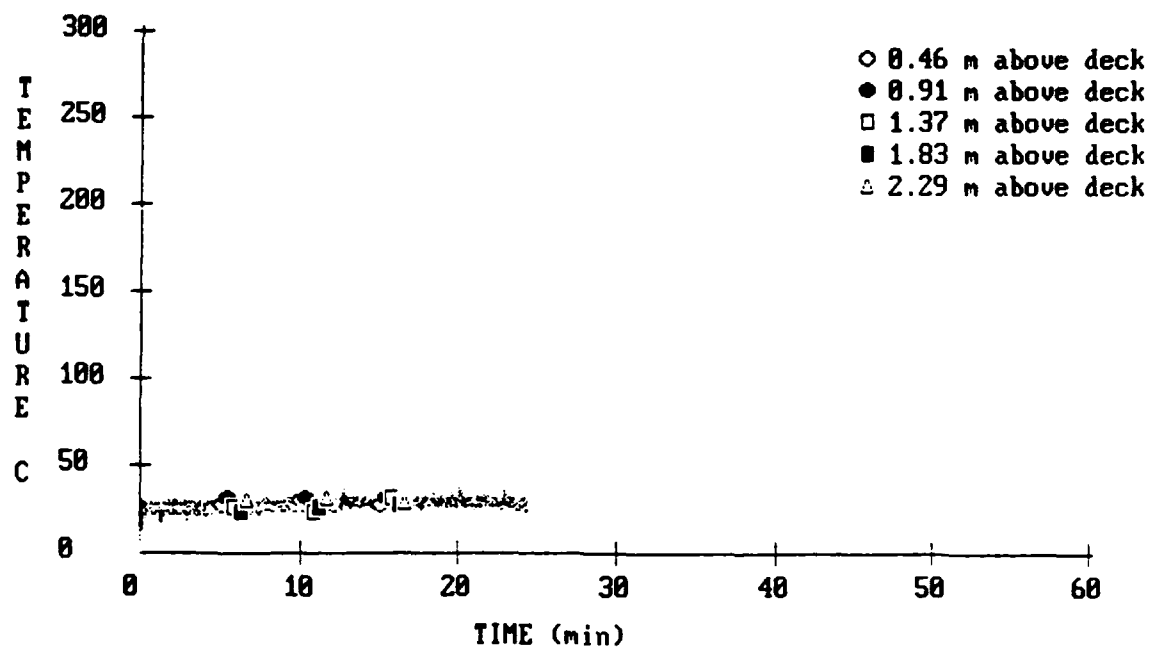


Fig. B-520- Temperature in RICER 1 (2-79-2) during Test # 14

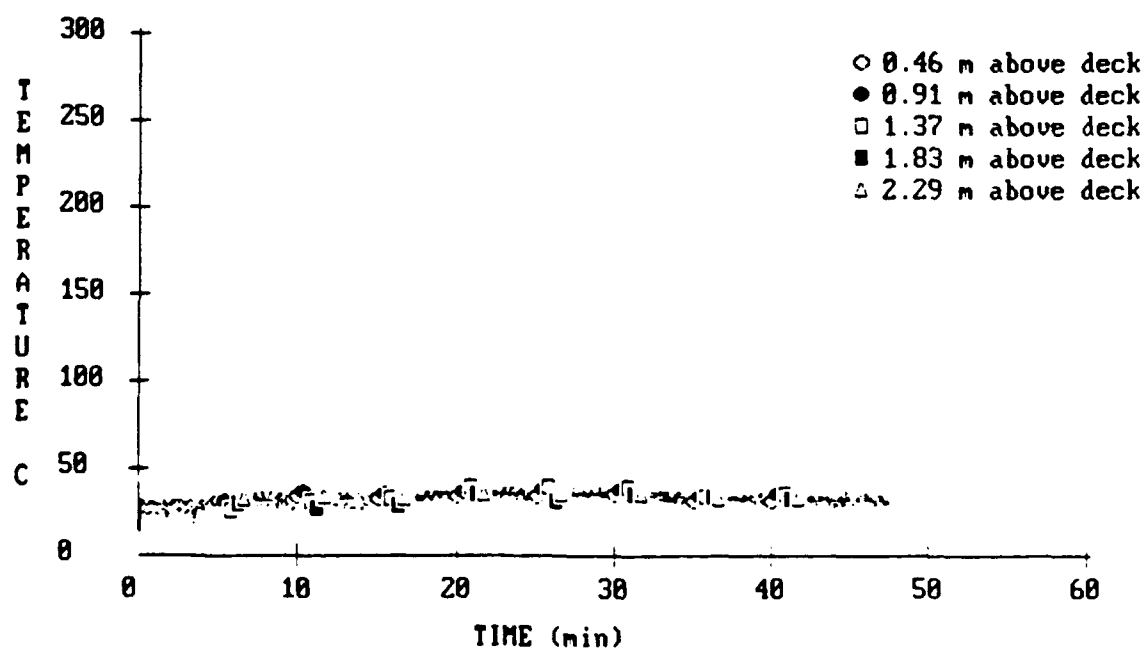


Fig. B-521- Temperature in RICER 1 (2-79-2) during Test # 15

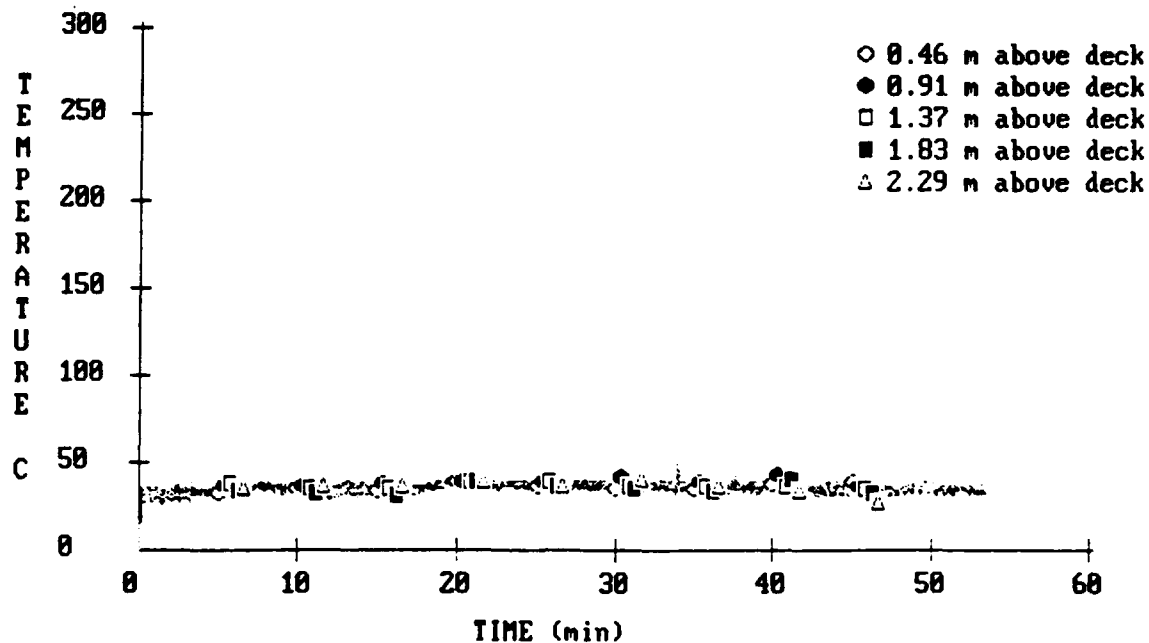


Fig. B-522- Temperature in RICER 1 (2-79-2) during Test # 16

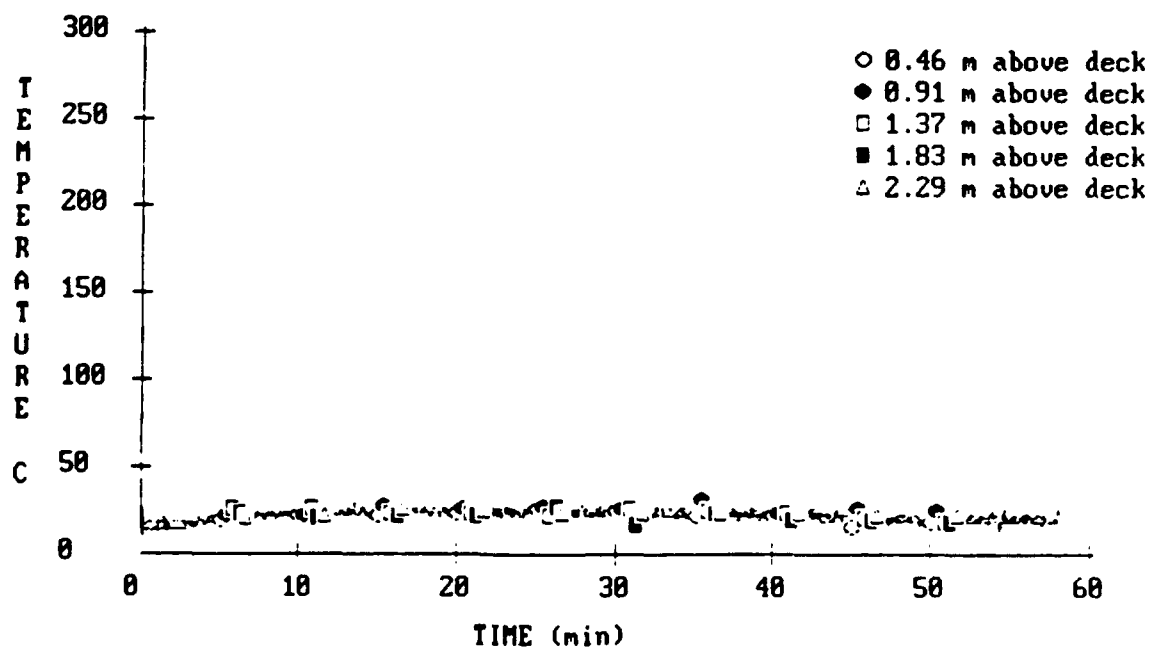


Fig. B-523- Temperature in RICER 1 (2-79-2) during Test # 17

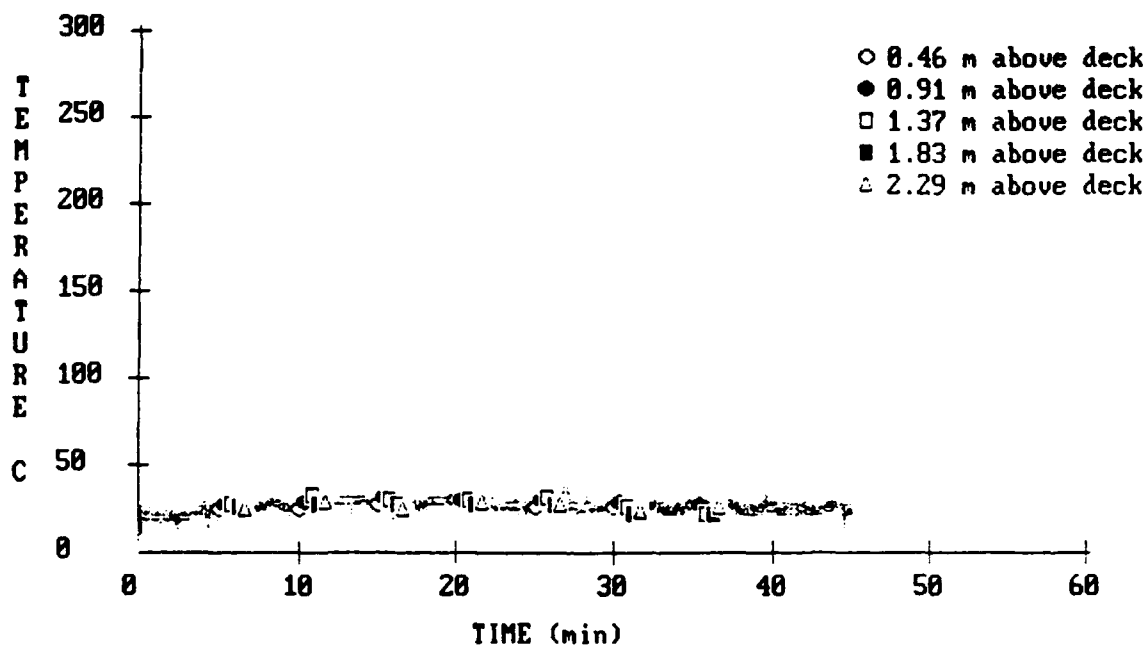


Fig. B-524- Temperature in RICER 1 (2-79-2) during Test # 18

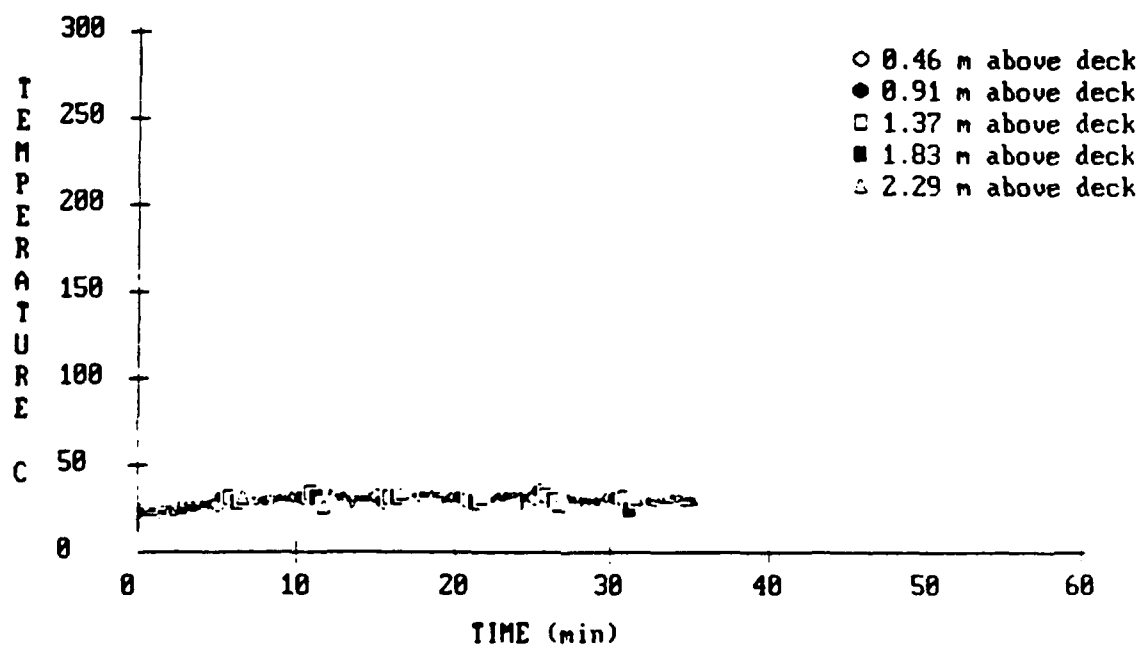


Fig. B-525- Temperature in RICER 1 (2-79-2) during Test # 19

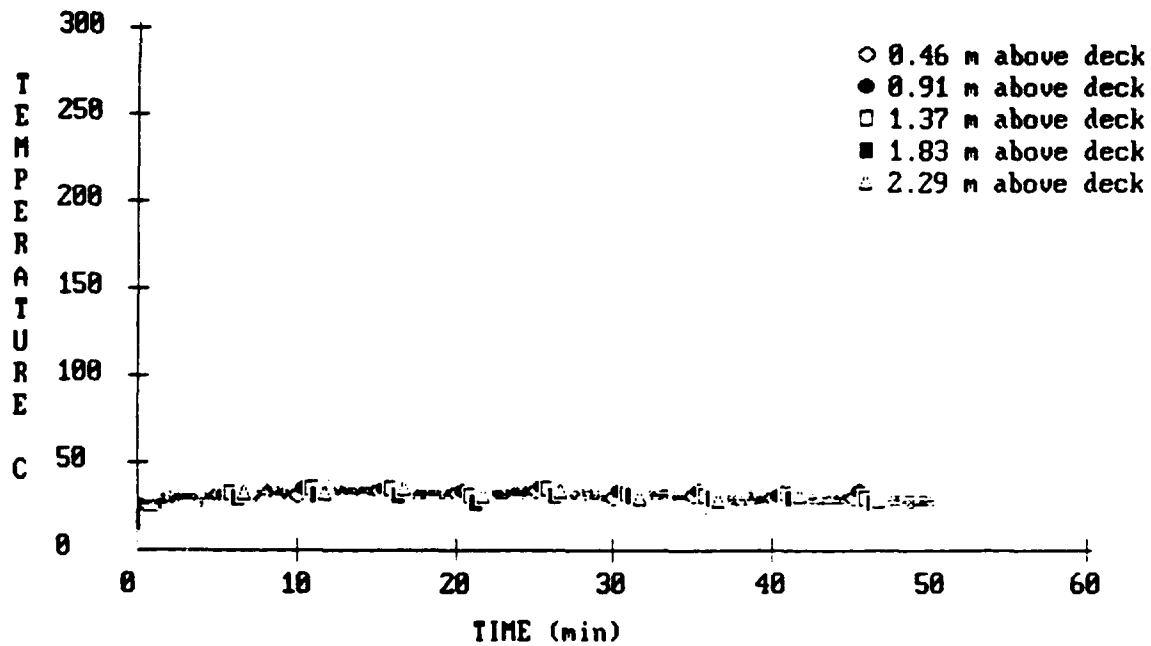


Fig. B-526- Temperature in RICER 1 (2-79-2) during Test # 20

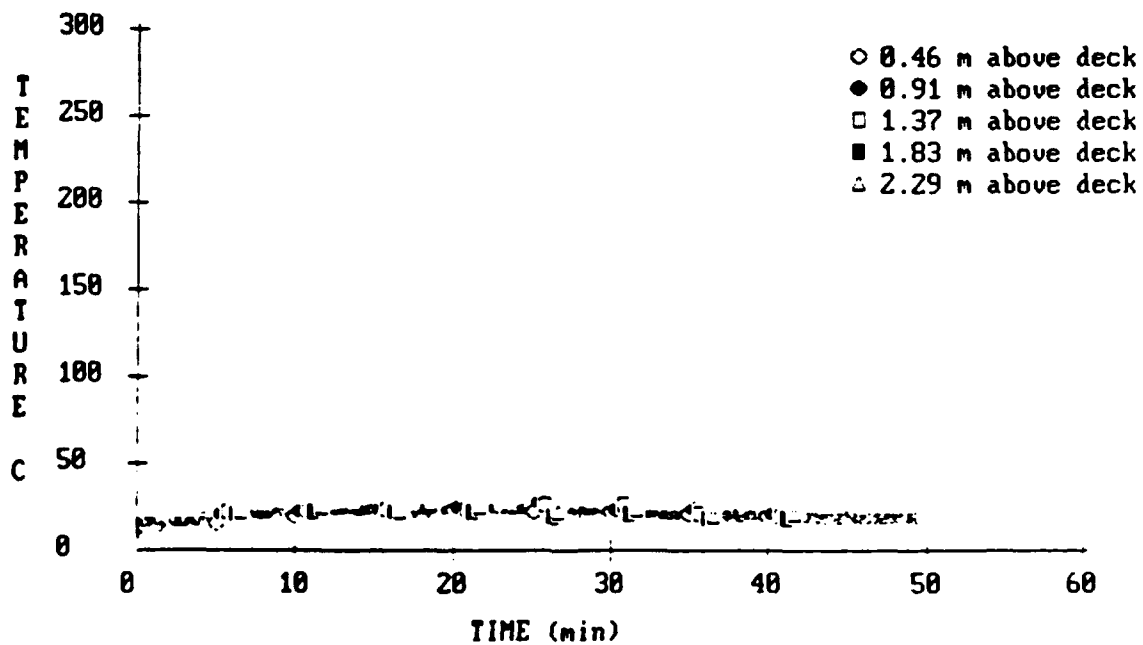


Fig. B-527- Temperature in RICER 1 (2-79-2) during Test # 21

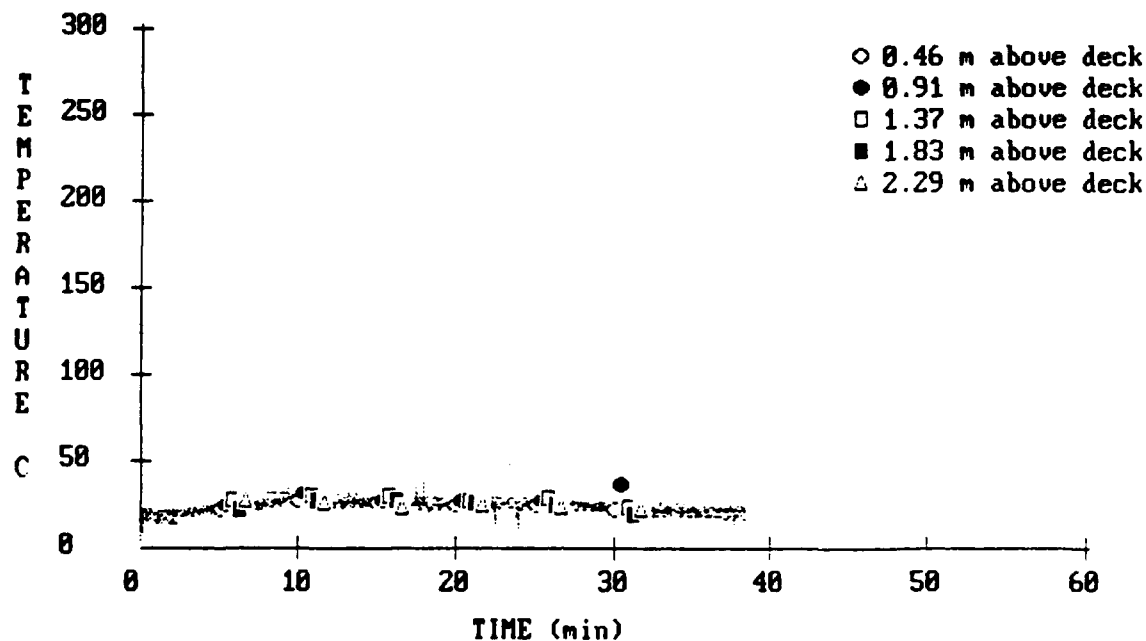


Fig. B-528- Temperature in RICER 1 (2-79-2) during Test # 22

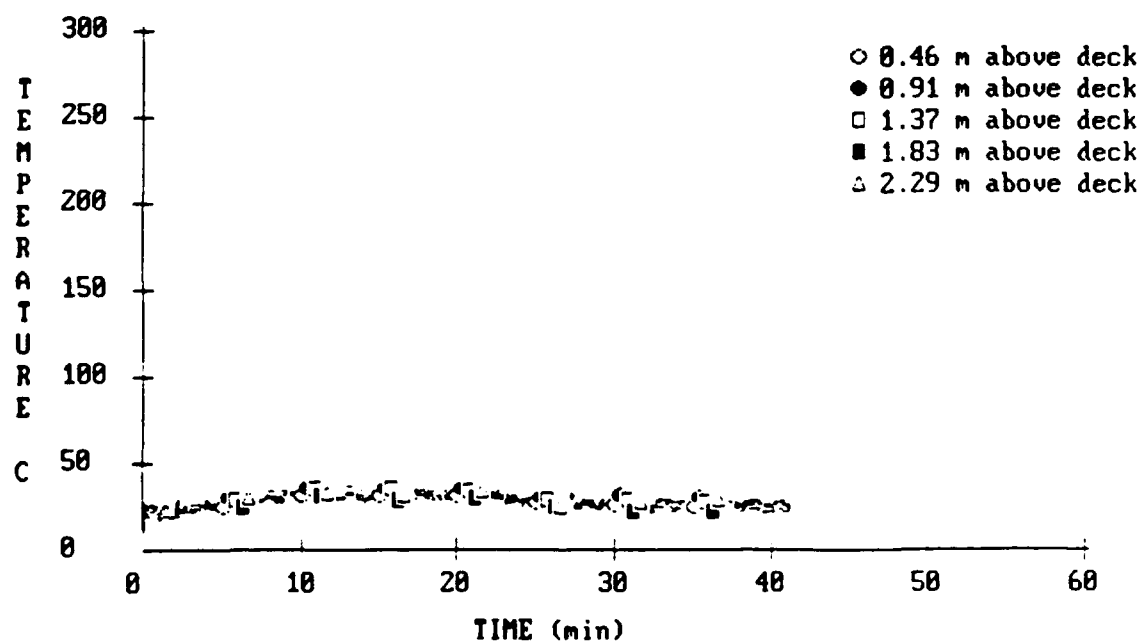


Fig. B-529- Temperature in RICER 1 (2-79-2) during Test # 23

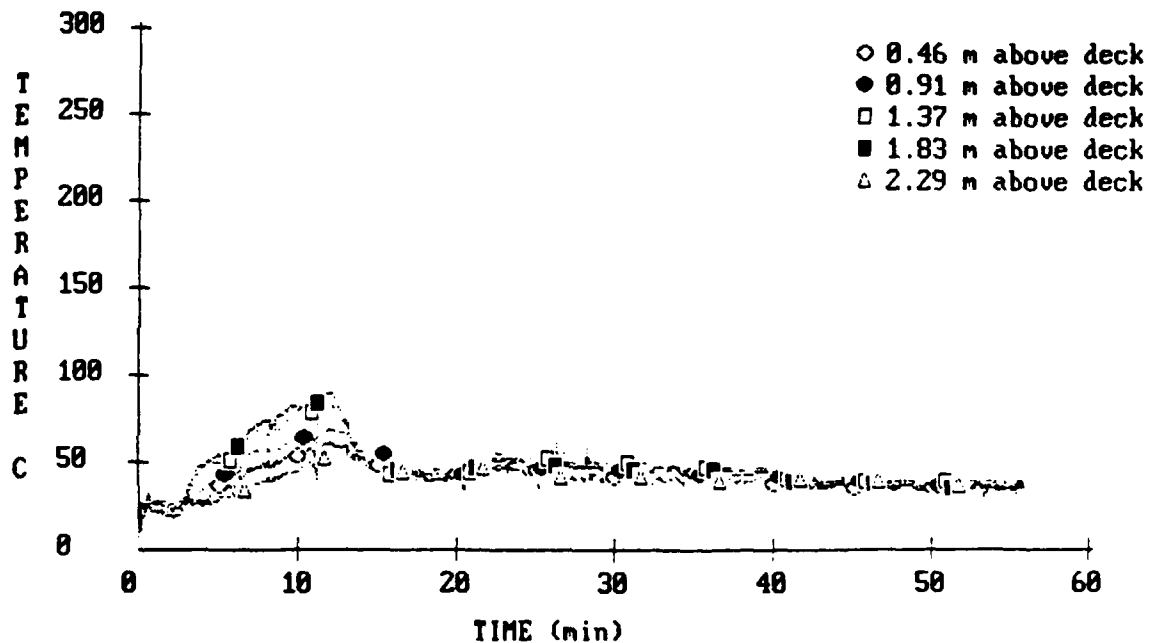


Fig. B-530- Temperature in RICER 1 (2-79-2) during Test # 24

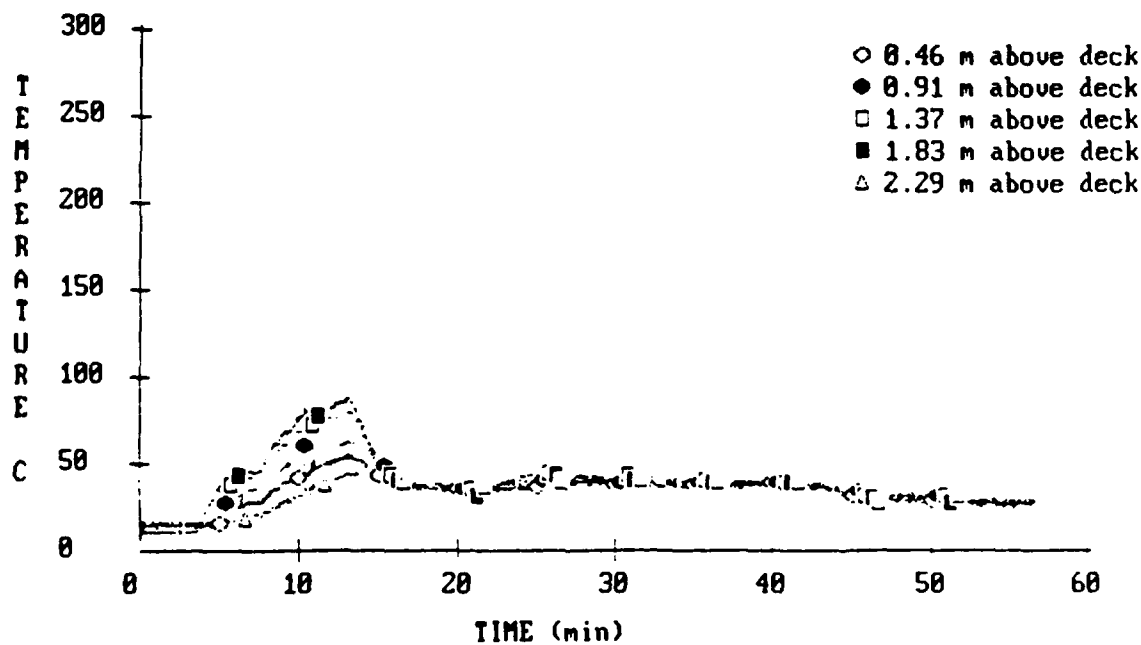


Fig. B-531- Temperature in RICER 1 (2-79-2) during Test # 25

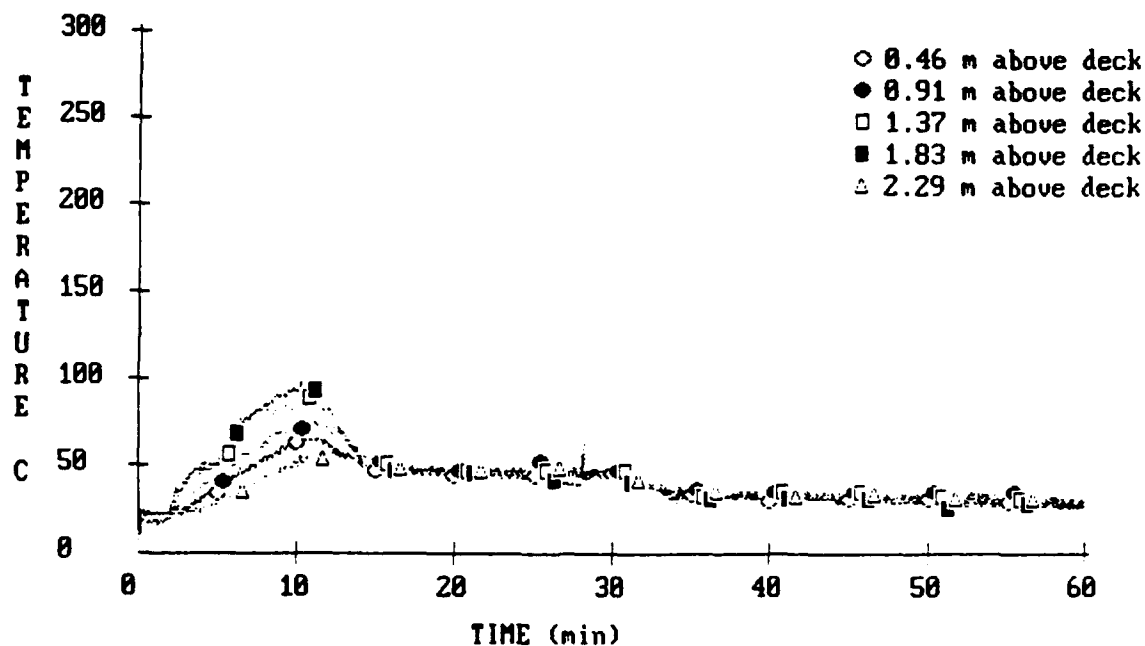


Fig. B-532- Temperature in RICER 1 (2-79-2) during Test # 26

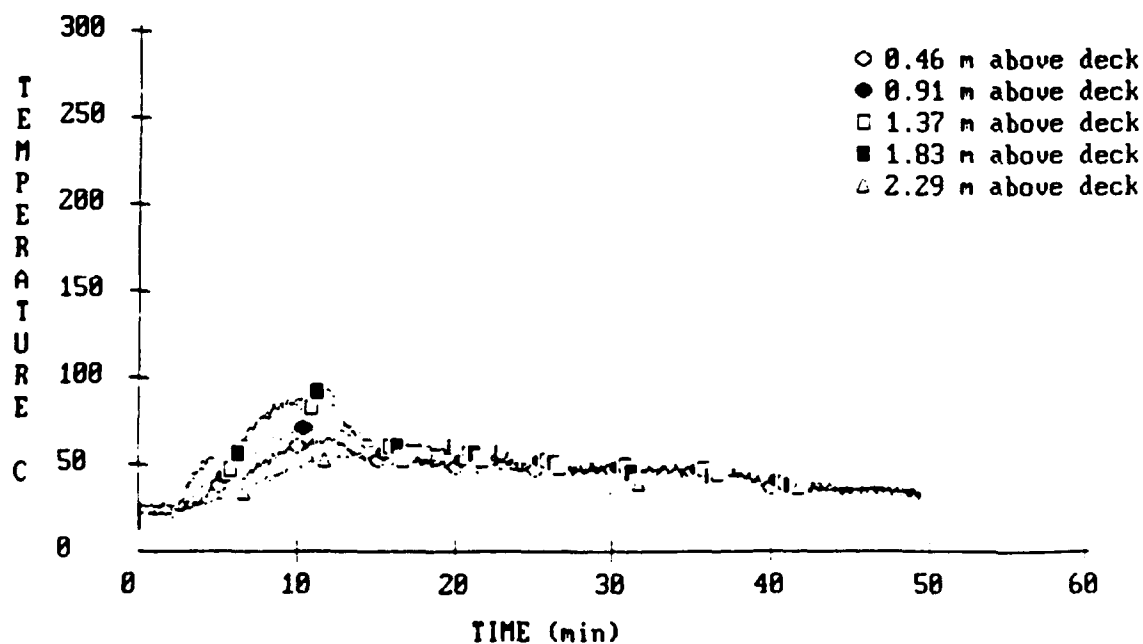


Fig. B-533- Temperature in RICER 1 (2-79-2) during Test # 27



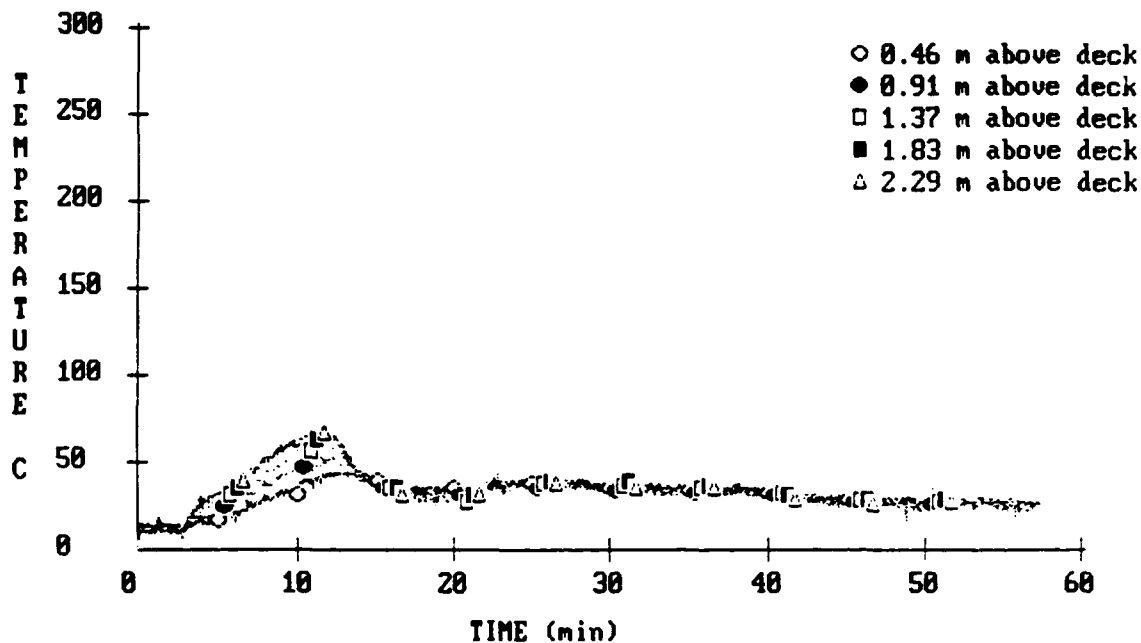


Fig. B-534- Temperature in RICER 1 (2-79-2) during Test # 28

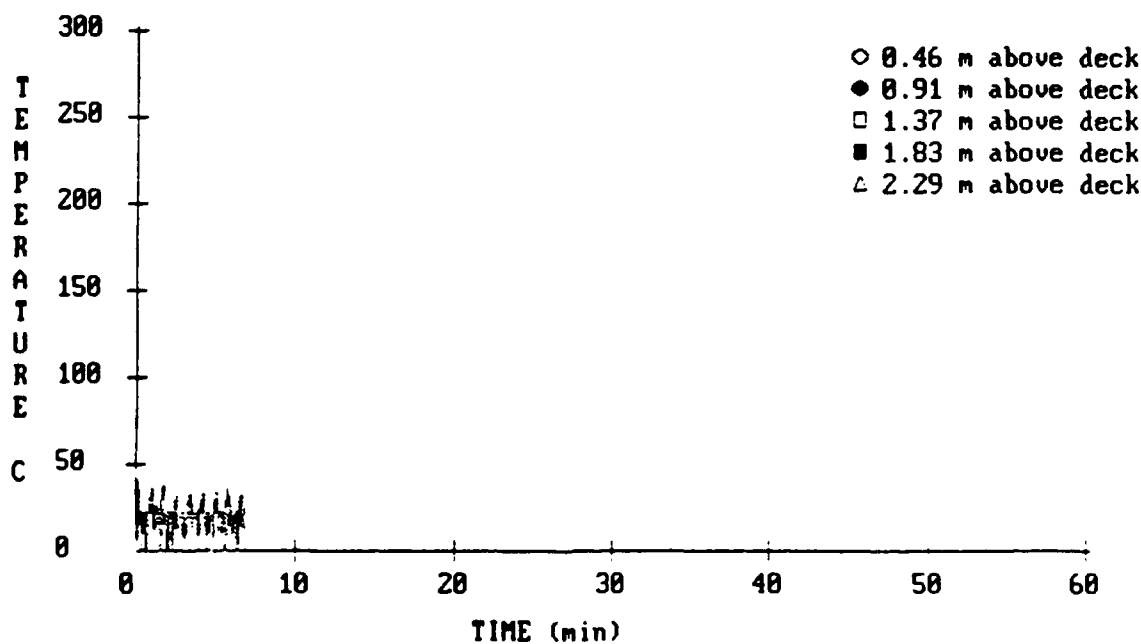


Fig. B-535- Temperature in RICER 1 (2-79-2) during Test # 29

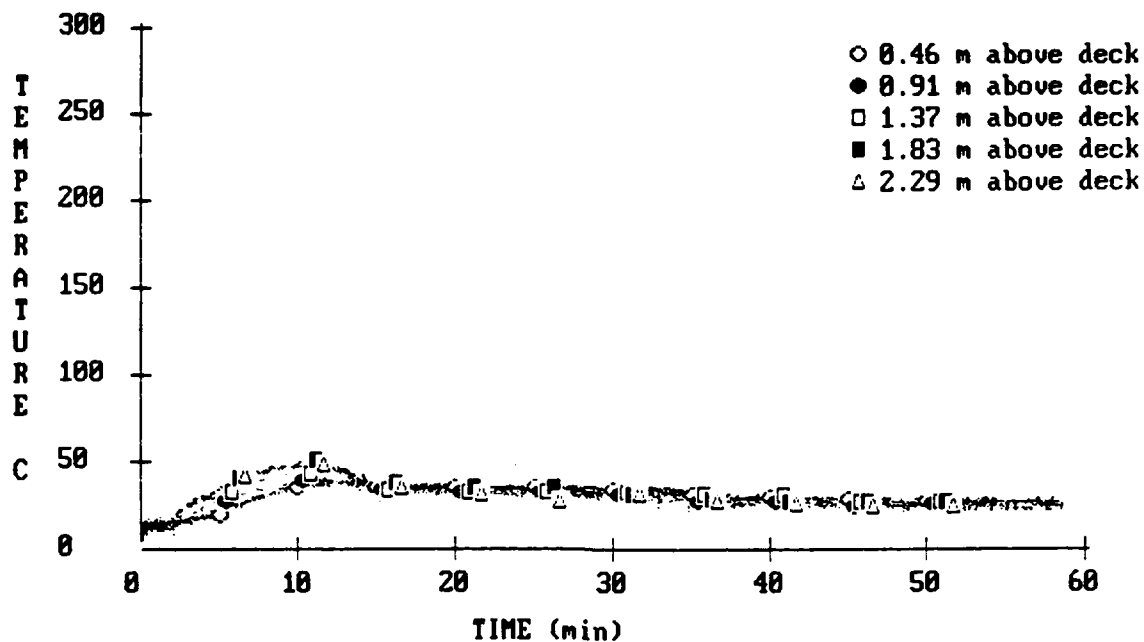


Fig. B-536- Temperature in RICER 1 (2-79-2) during Test # 30

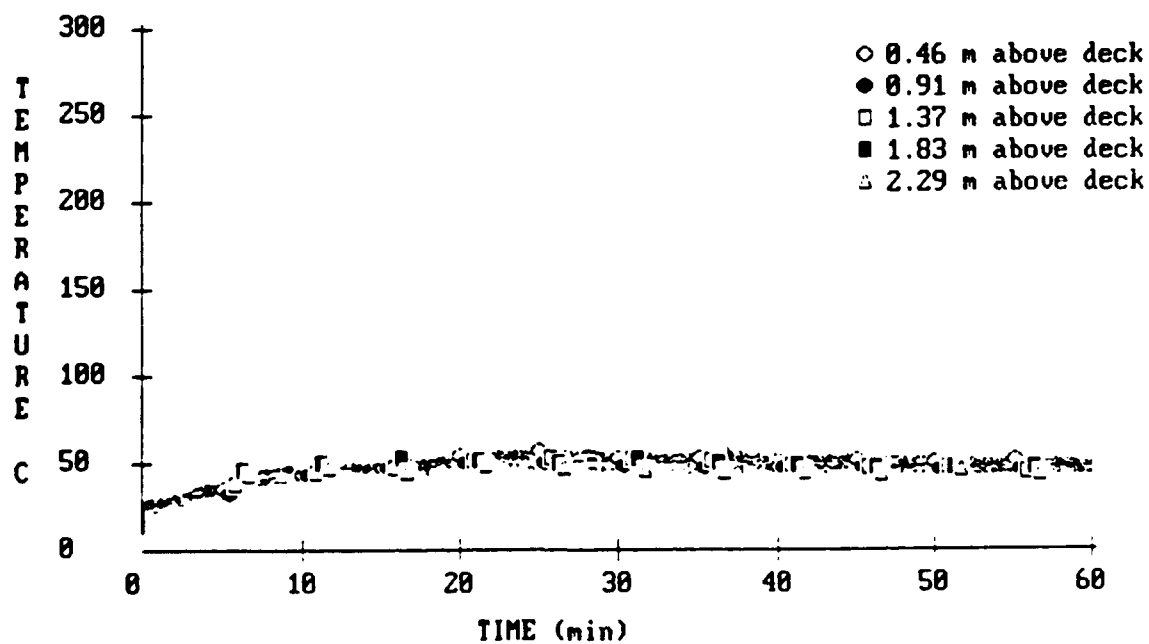


Fig. B-537- Temperature in RICER 1 (2-79-2) during Test # 31

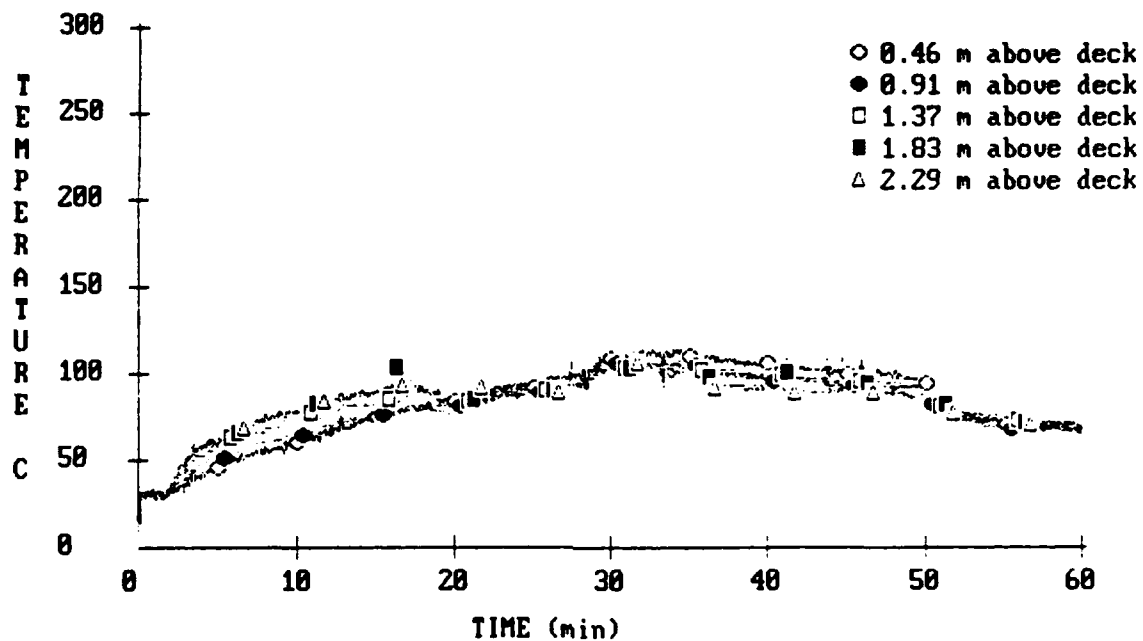


Fig. B-538- Temperature in RICER 1 (2-79-2) during Test # 32

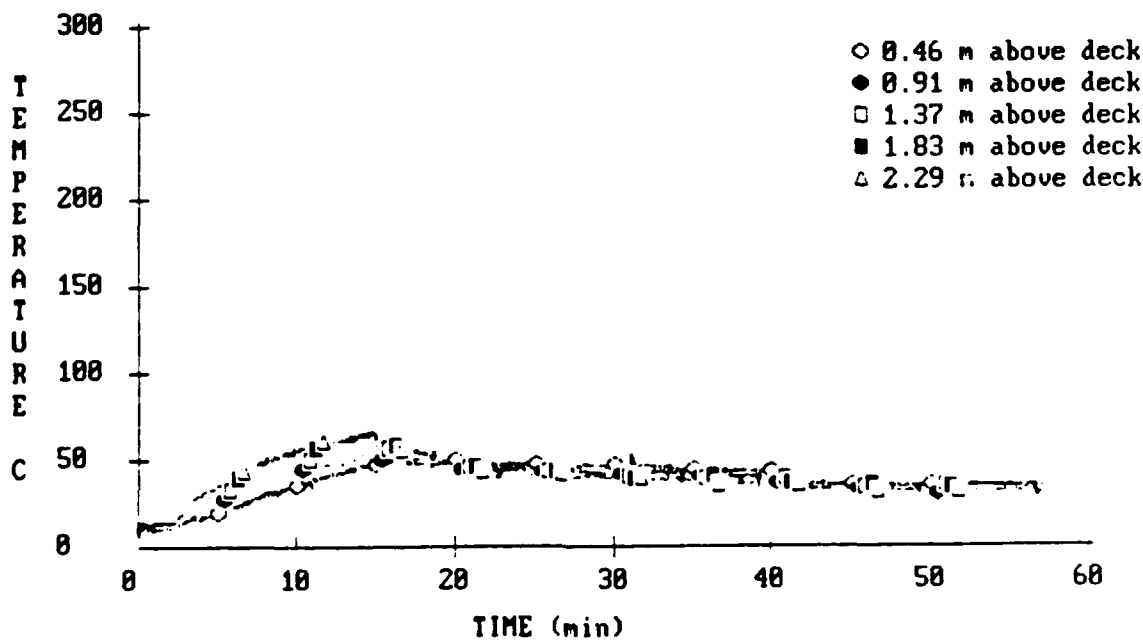


Fig. B-539- Temperature in RICER 1 (2-79-2) during Test # 33

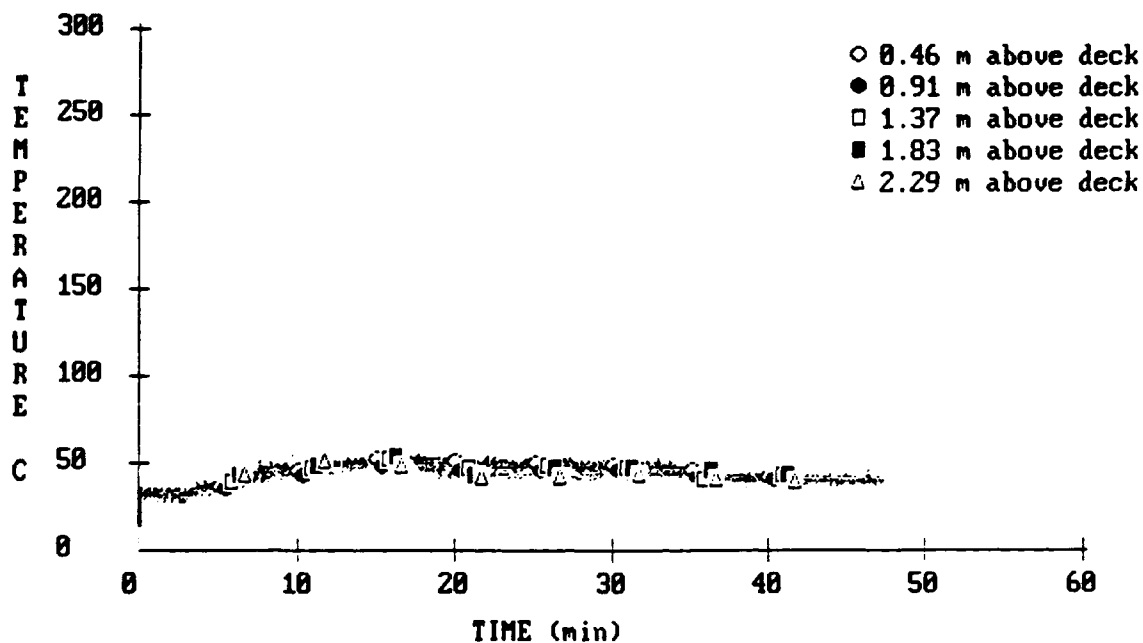


Fig. B-540- Temperature in RICER 1 (2-79-2) during Test # 34

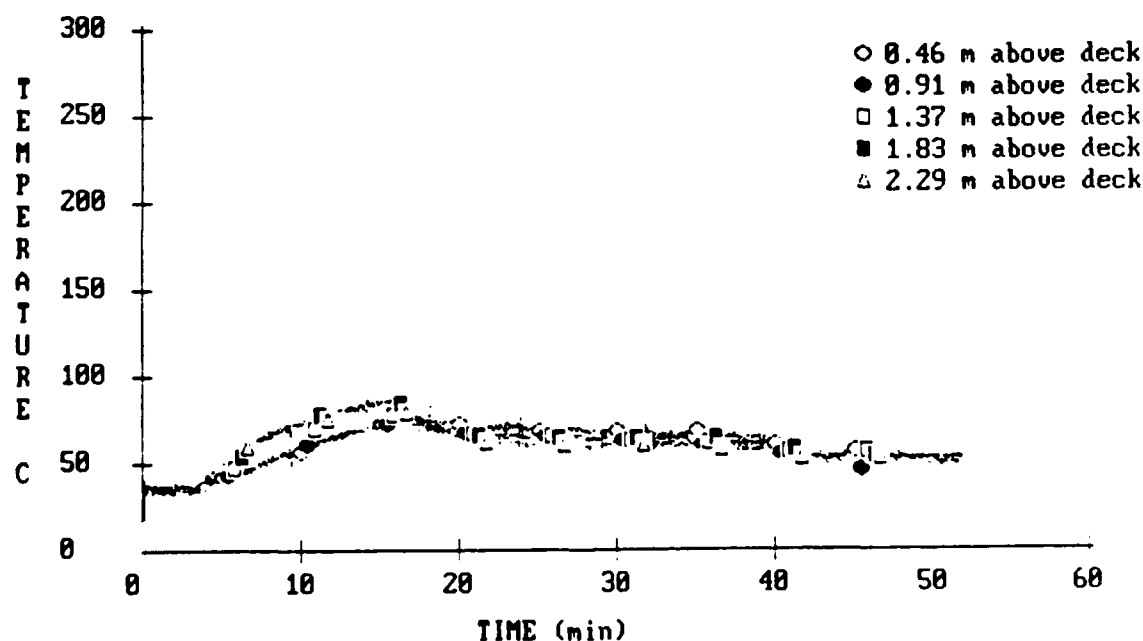


Fig. B-541- Temperature in RICER 1 (2-79-2) during Test # 35

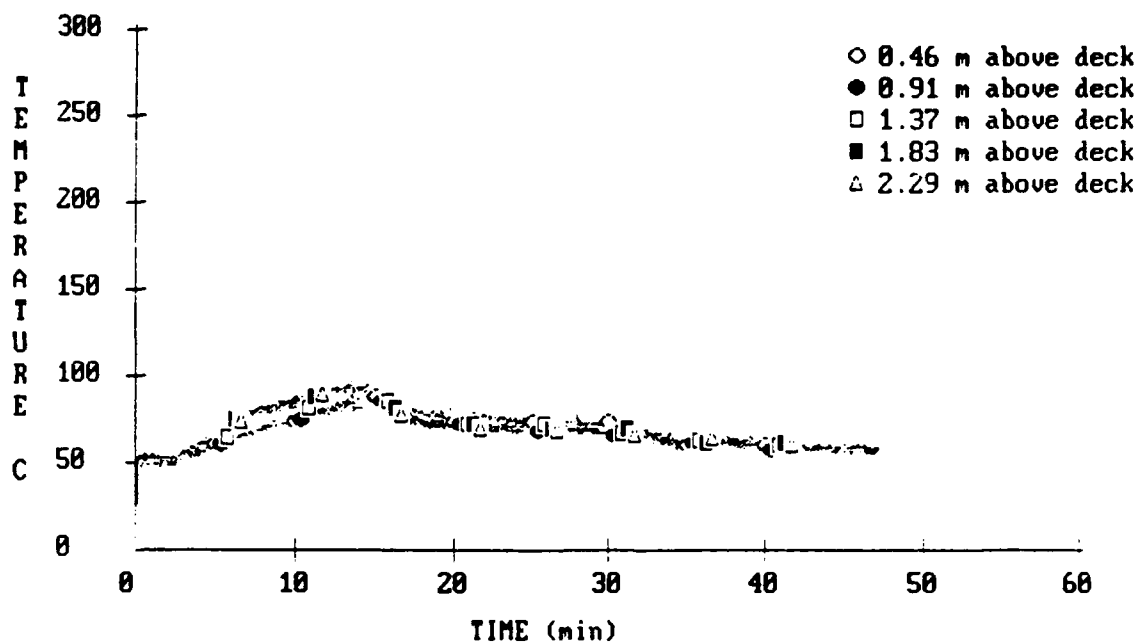


Fig. B-542- Temperature in RICER 1 (2-79-2) during Test # 36

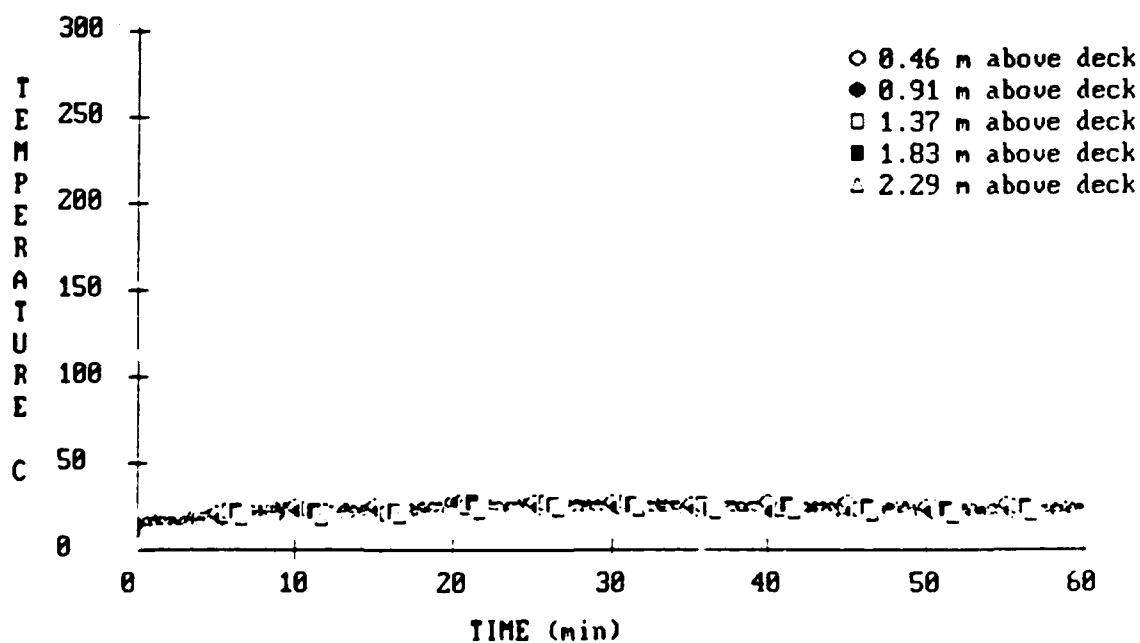


Fig. B-543- Temperature in RICER 1 (2-79-2) during Test # 37

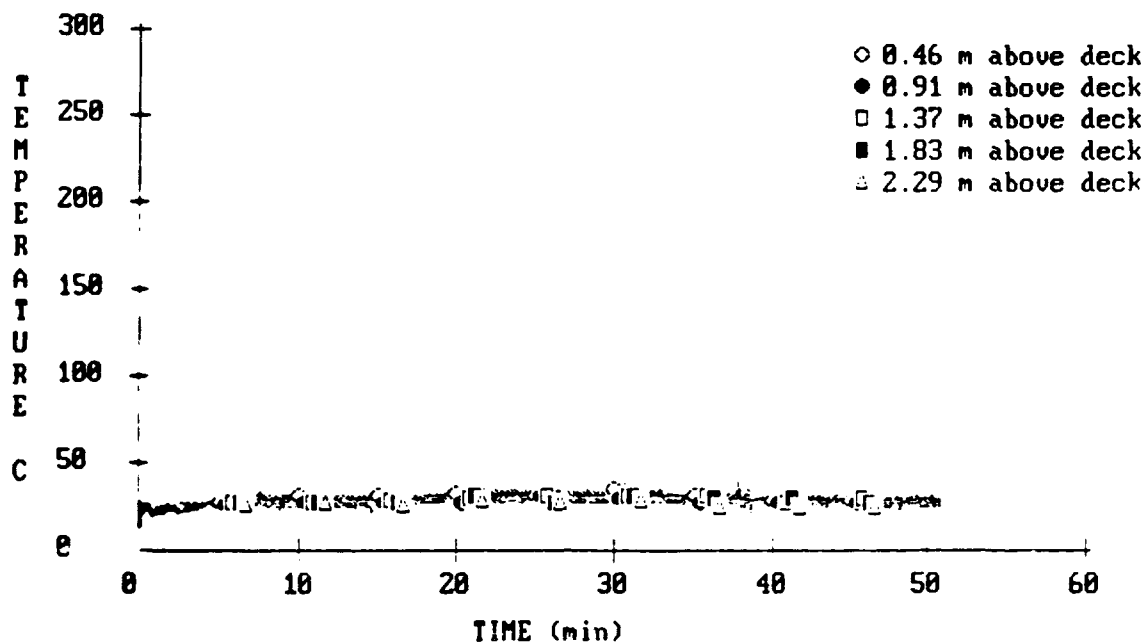


Fig. B-544- Temperature in RICER 1 (2-79-2) during Test # 38

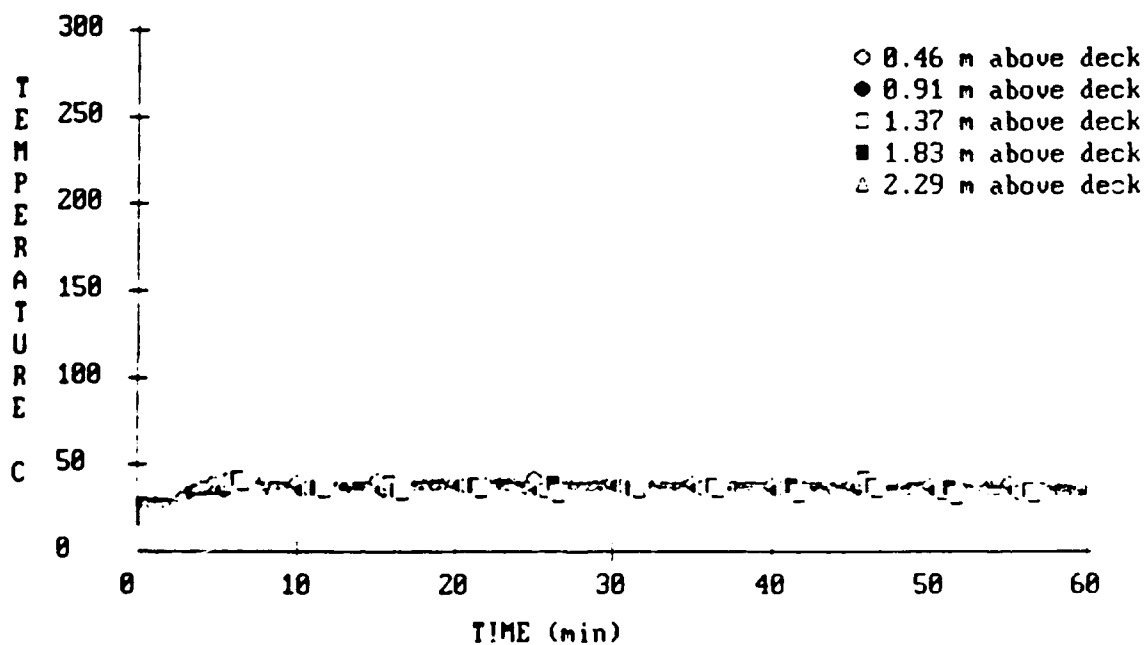


Fig. B-545- Temperature in RICER 1 (2-79-2) during Test # 39

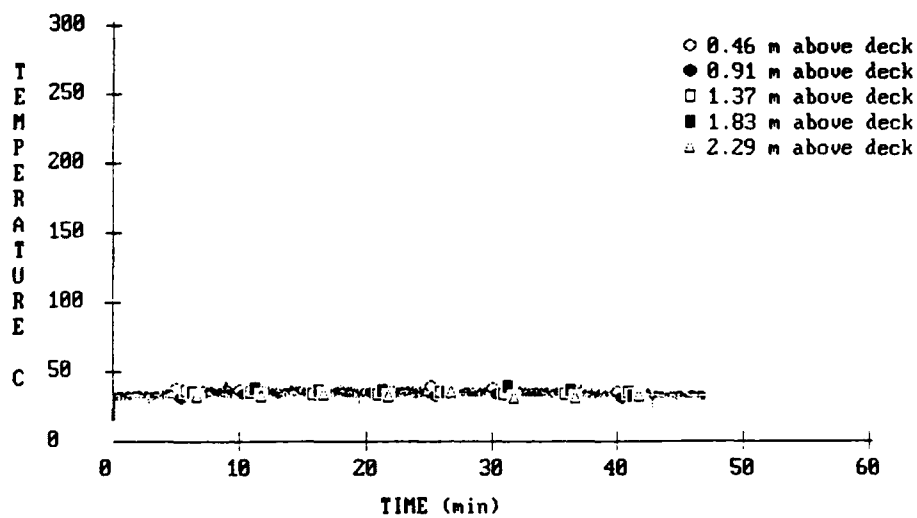


Fig. B-546- Temperature in RICER 1 (2-79-2) during Test # 40

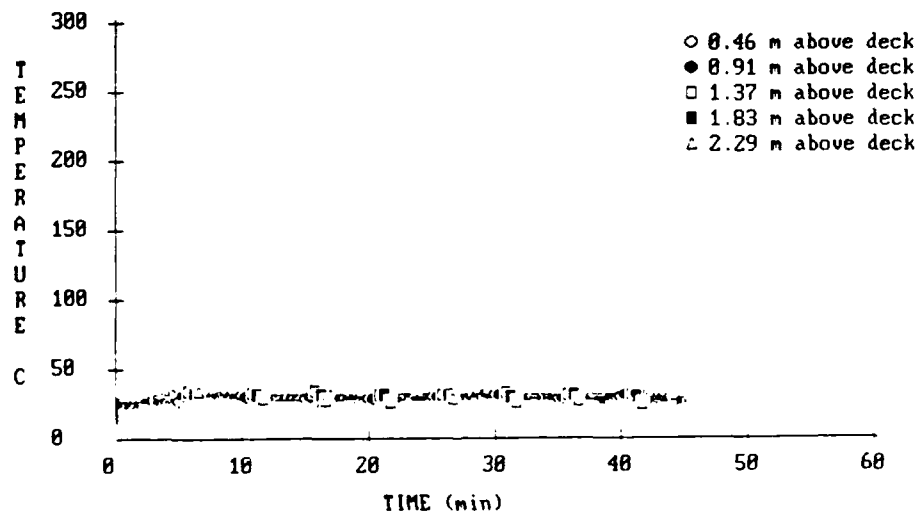


Fig. B-547- Temperature in RICER 1 (2-76-2) during Test # 2

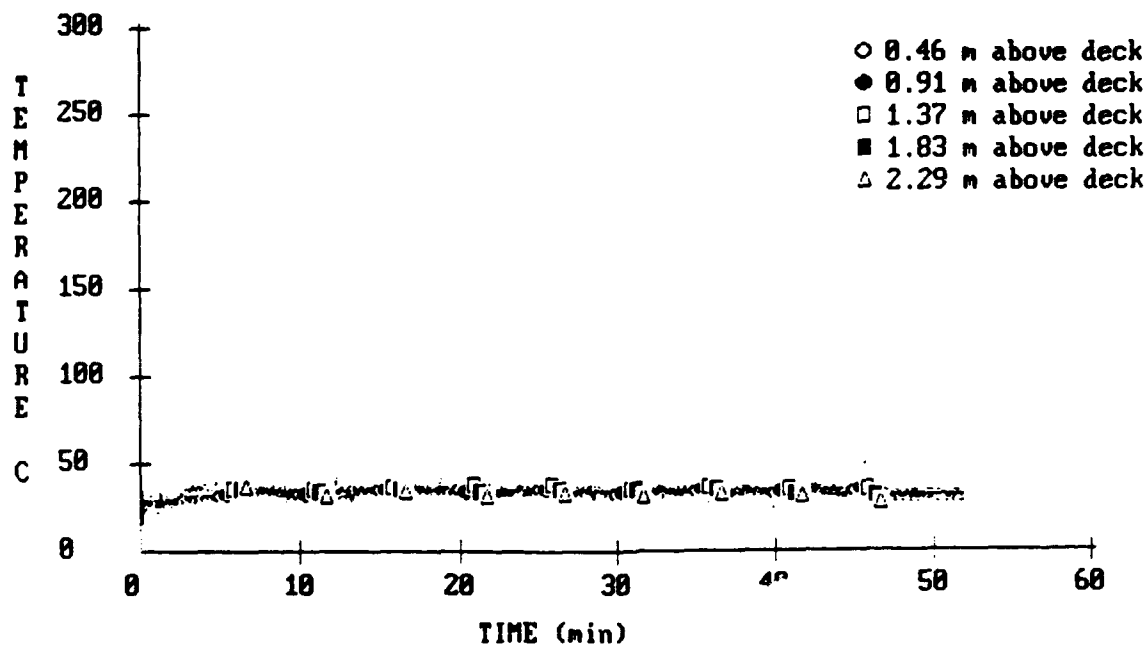


Fig. B-548- Temperature in RICER 1 (2-76-2) during Test # 3

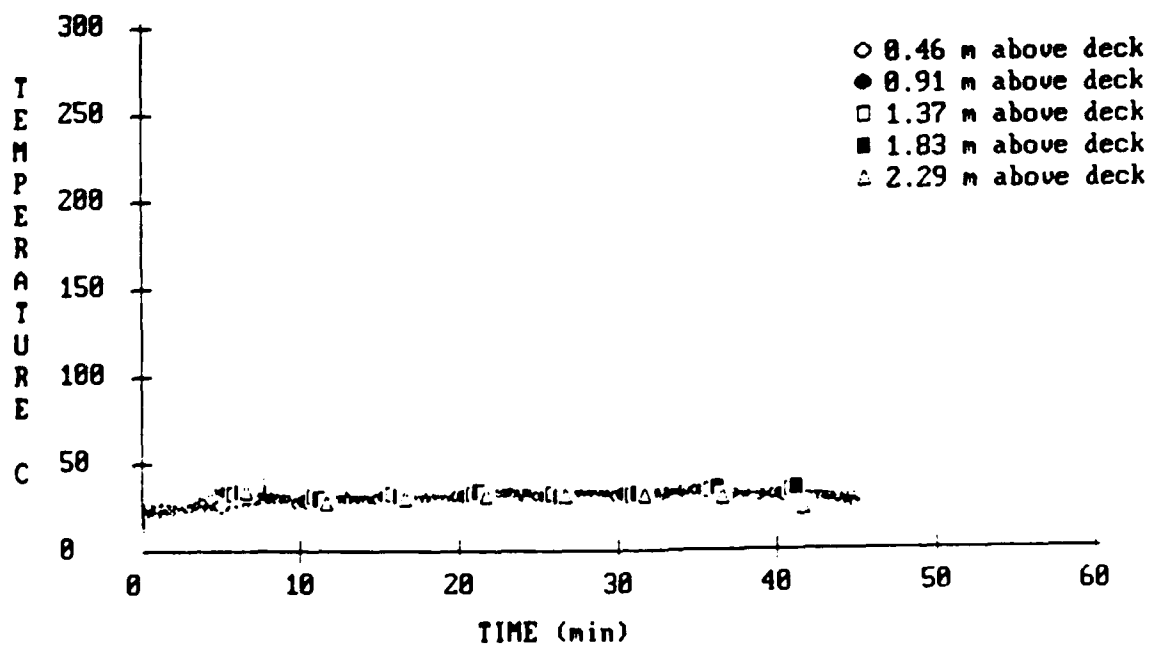


Fig. B-549- Temperature in RICER 1 (2-76-2) during Test # 4



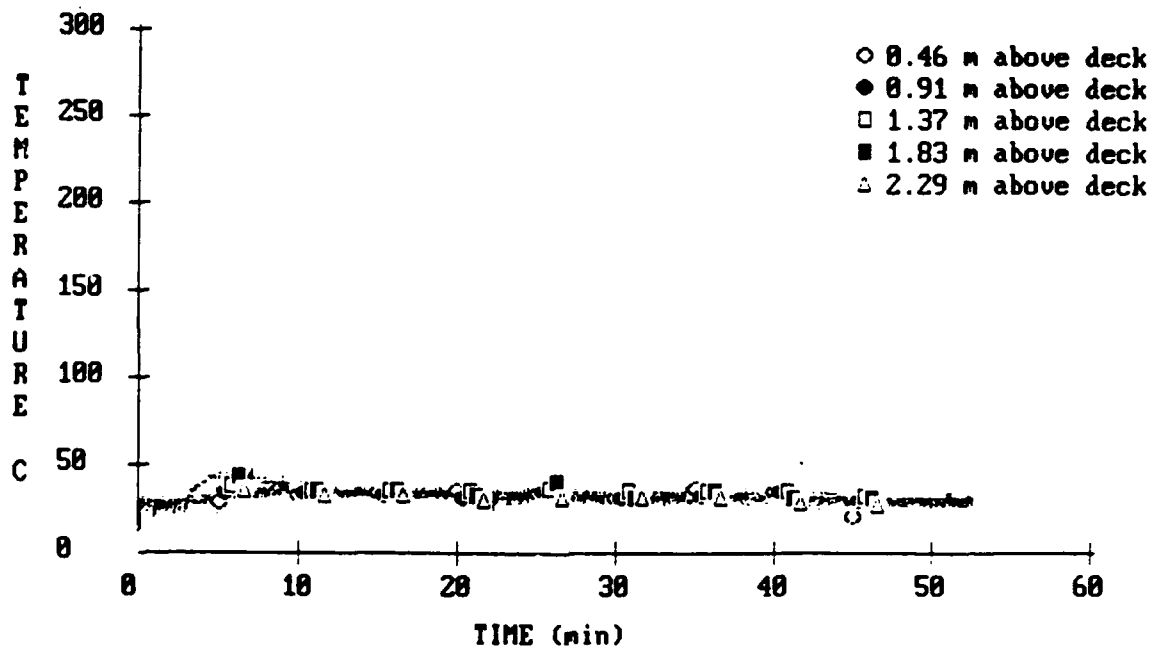


Fig. B-550- Temperature in RICER 1 (2-76-2) during Test # 5

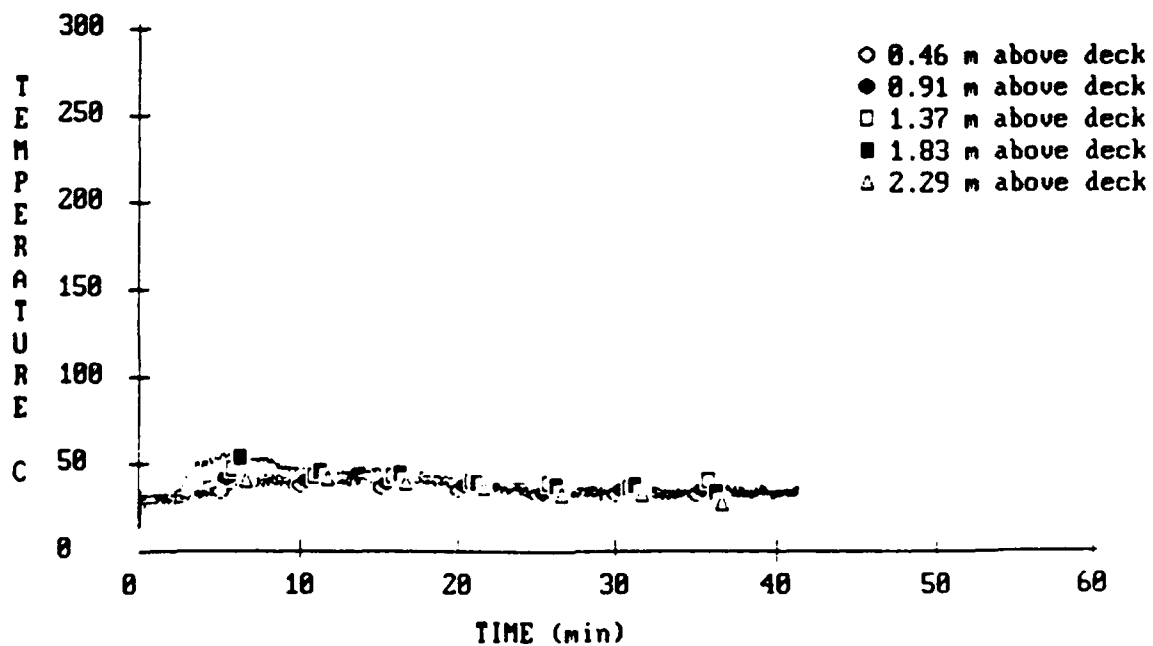


Fig. B-551- Temperature in RICER 1 (2-76-2) during Test # 6

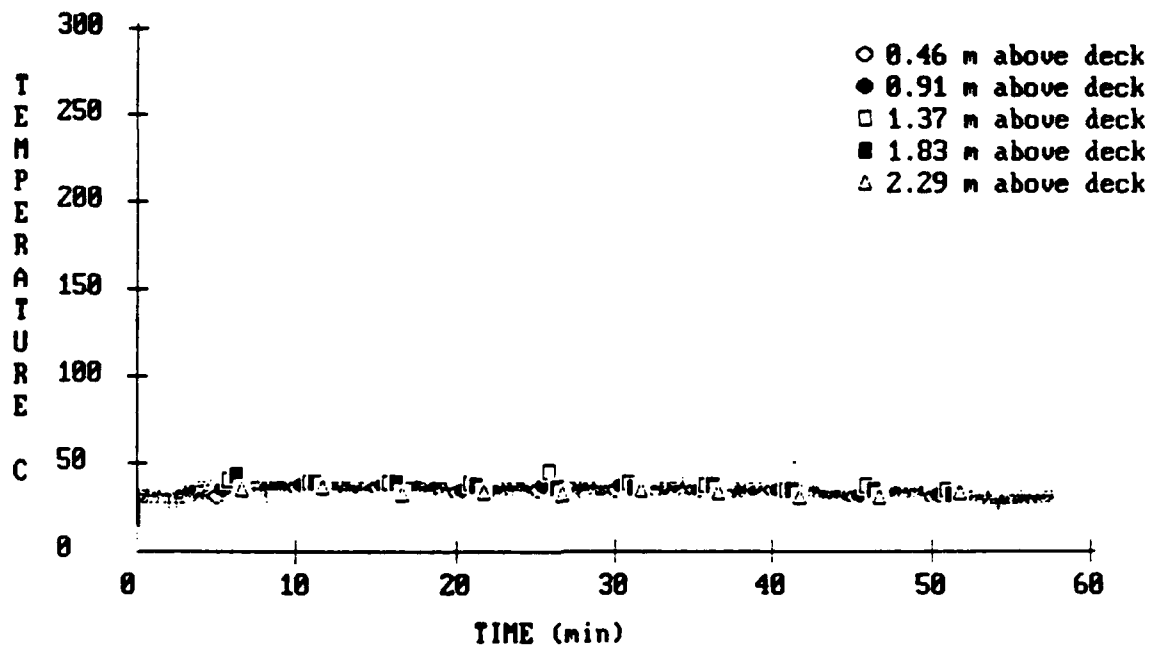


Fig. B-552- Temperature in RICER 1 (2-76-2) during Test # 7

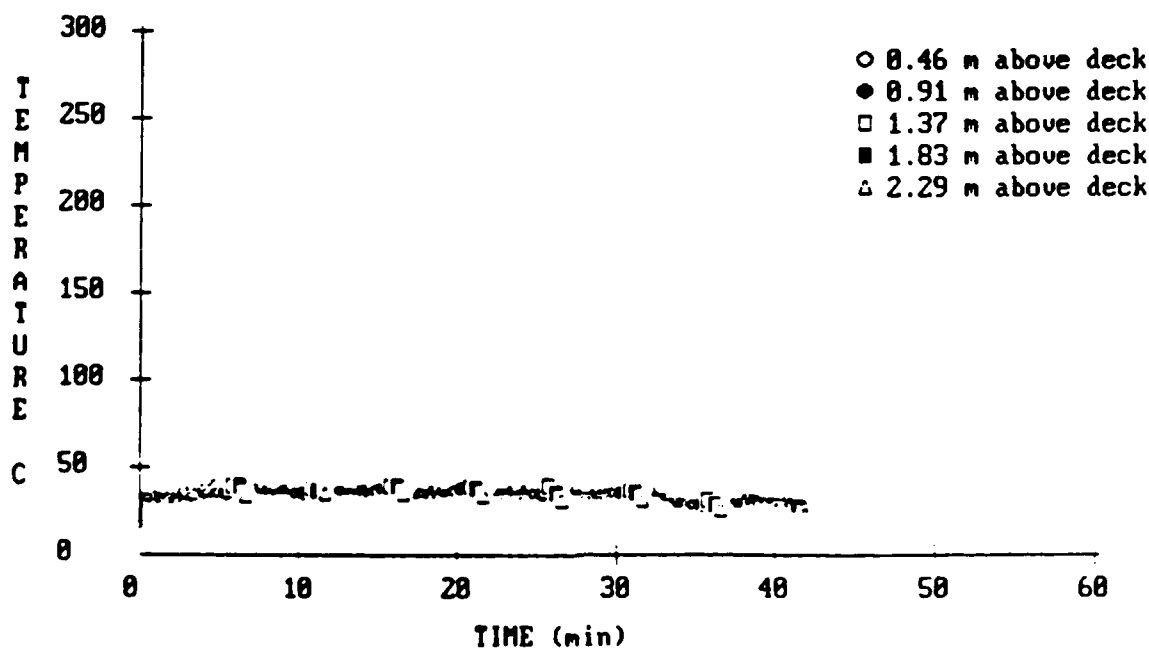


Fig. B-553- Temperature in RICER 1 (2-76-2) during Test # 8

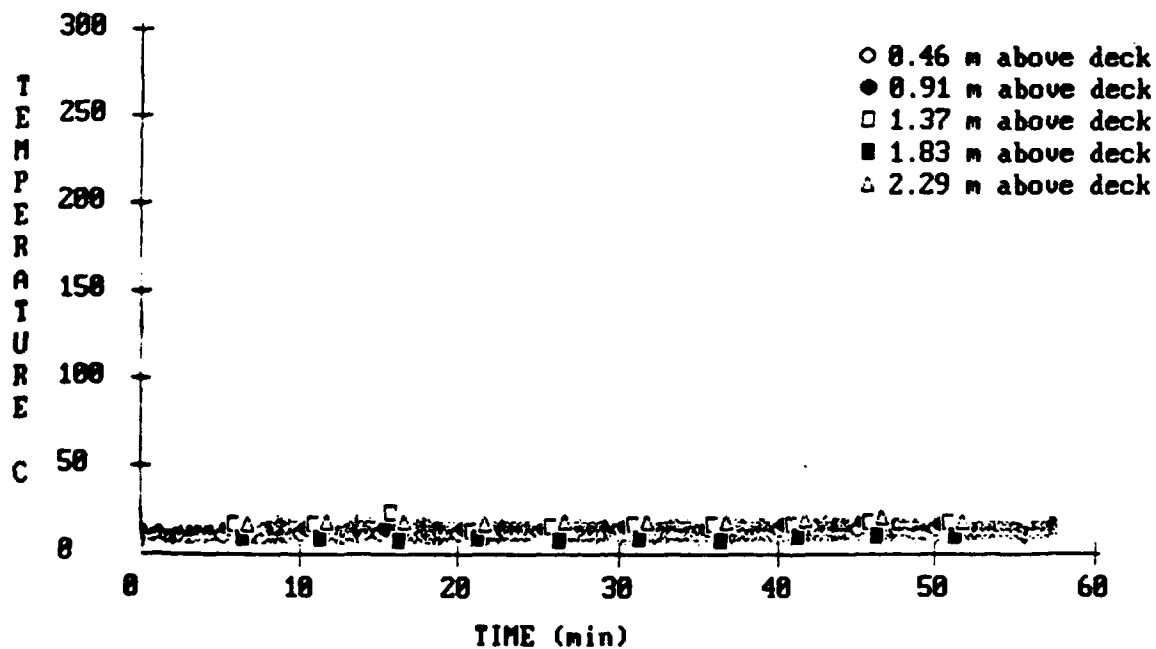


Fig. B-554- Temperature in RICER 1 (2-76-2) during Test # 9

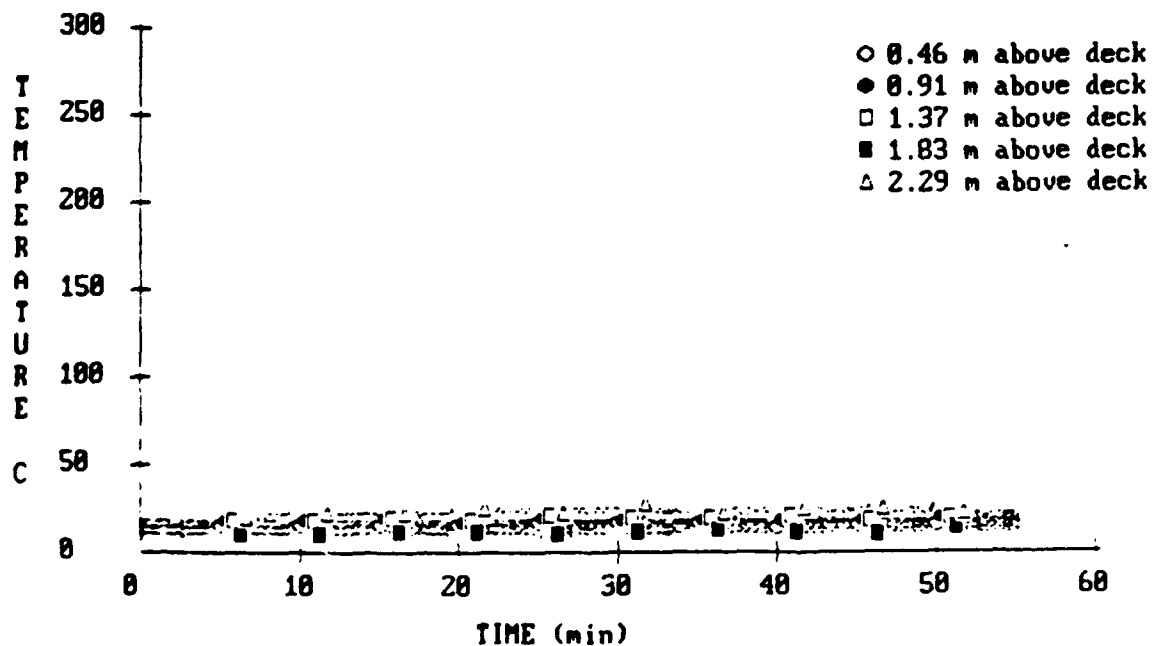


Fig. B-555- Temperature in RICER 1 (2-76-2) during Test # 10

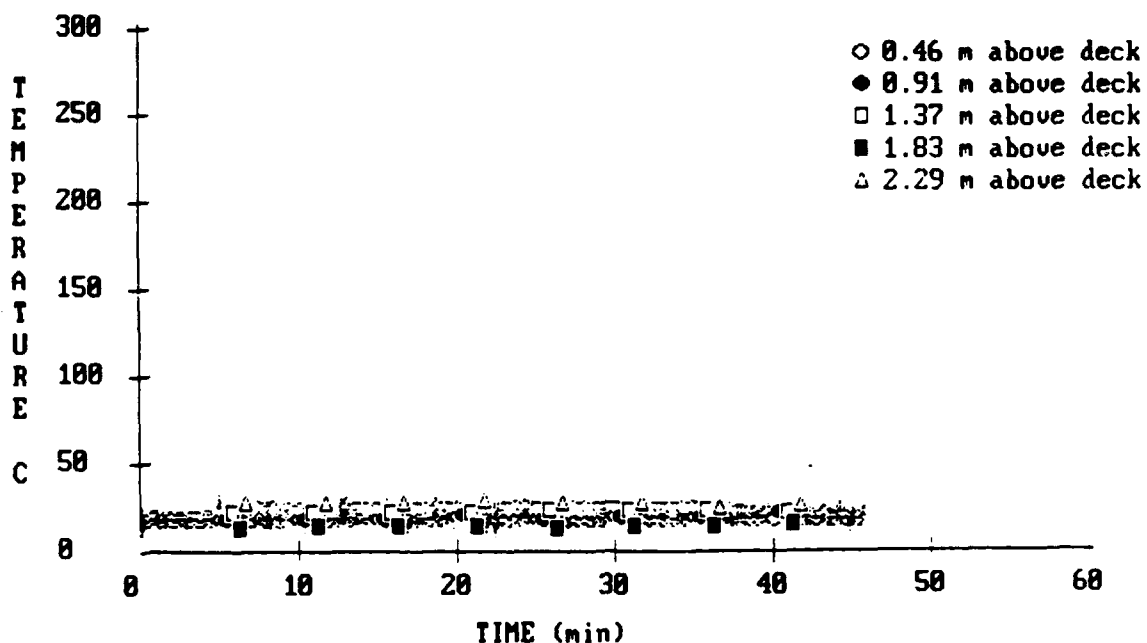


Fig. B-556- Temperature in RICER 1 (2-76-2) during Test # 11

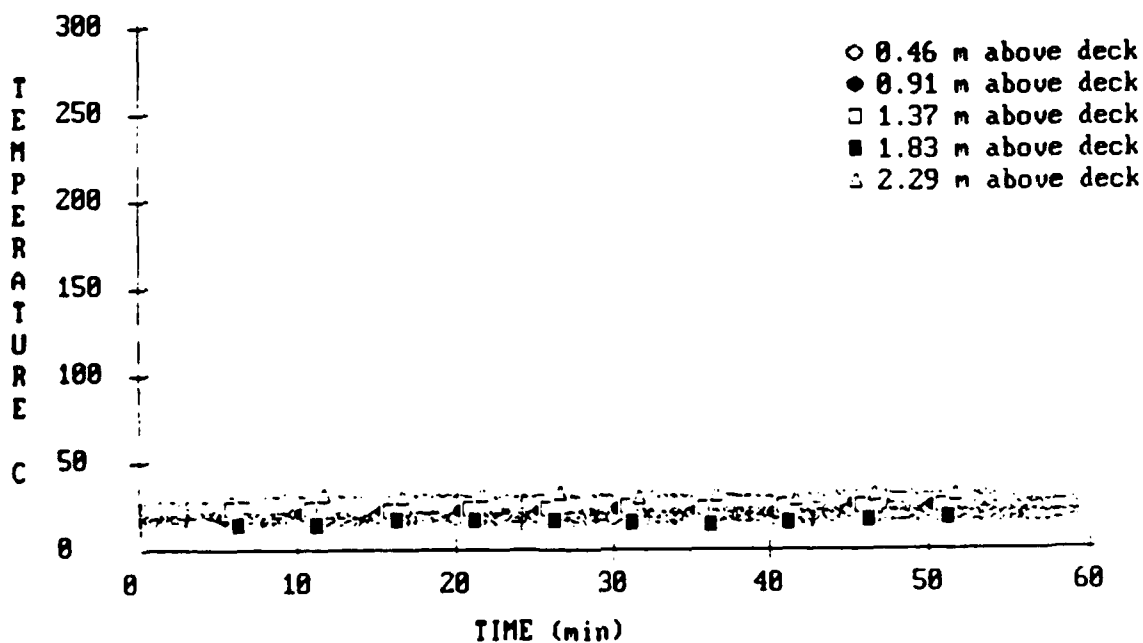


Fig. B-557- Temperature in RICER 1 (2-76-2) during Test # 12

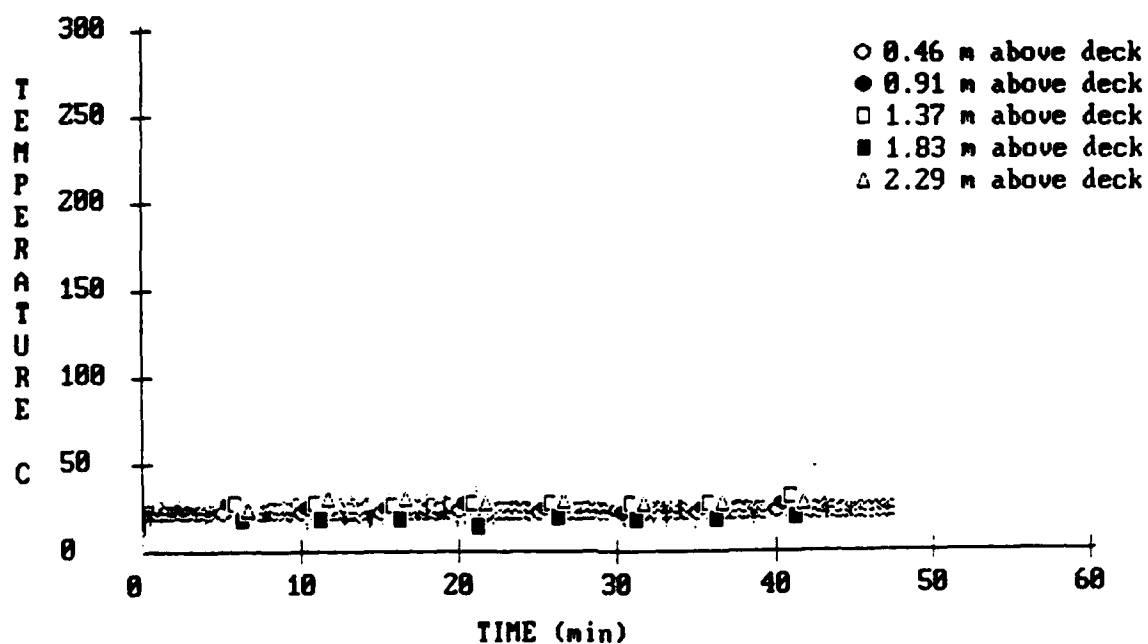


Fig. B-558- Temperature in RICER 1 (2-76-2) during Test # 13

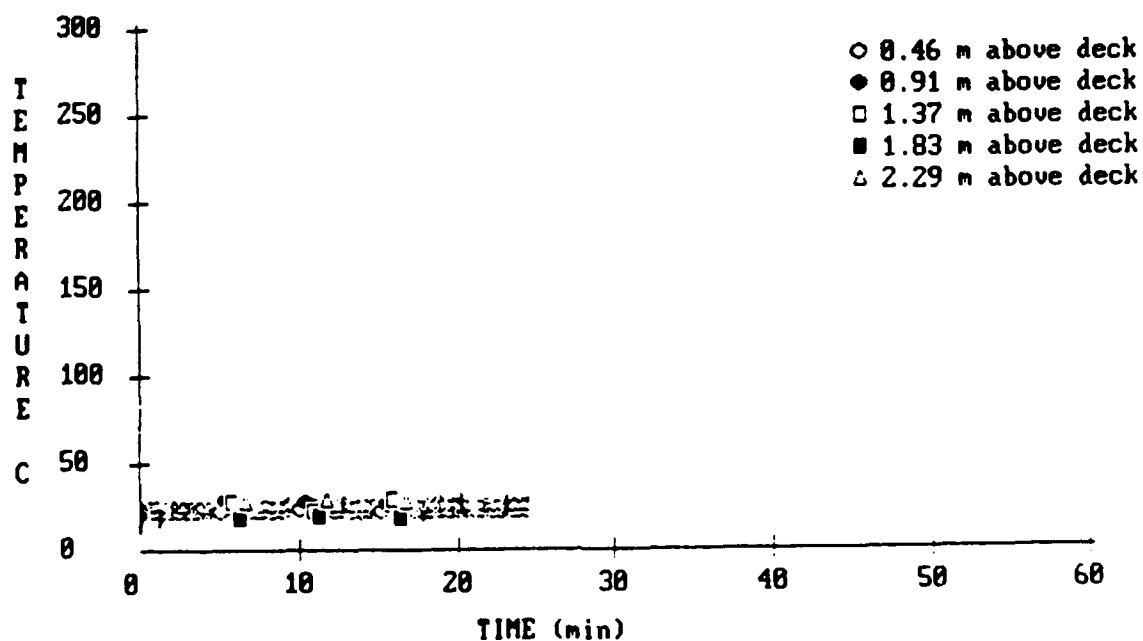


Fig. B-559- Temperature in RICER 1 (2-76-2) during Test # 14

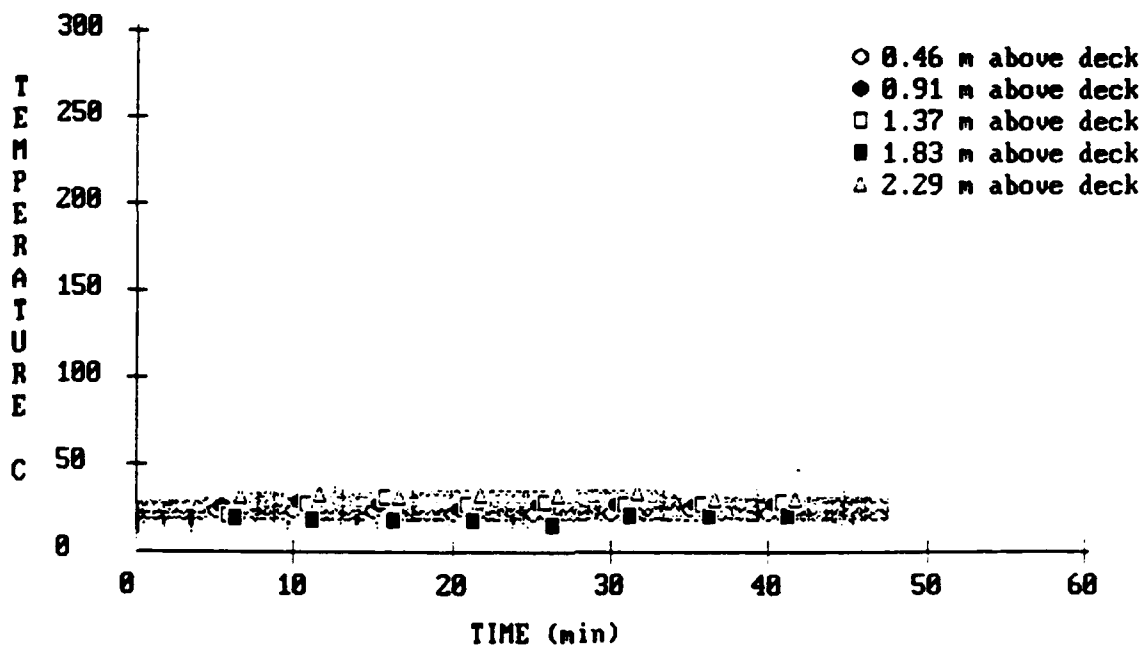


Fig. B-560- Temperature in RICER 1 (2-76-2) during Test # 15

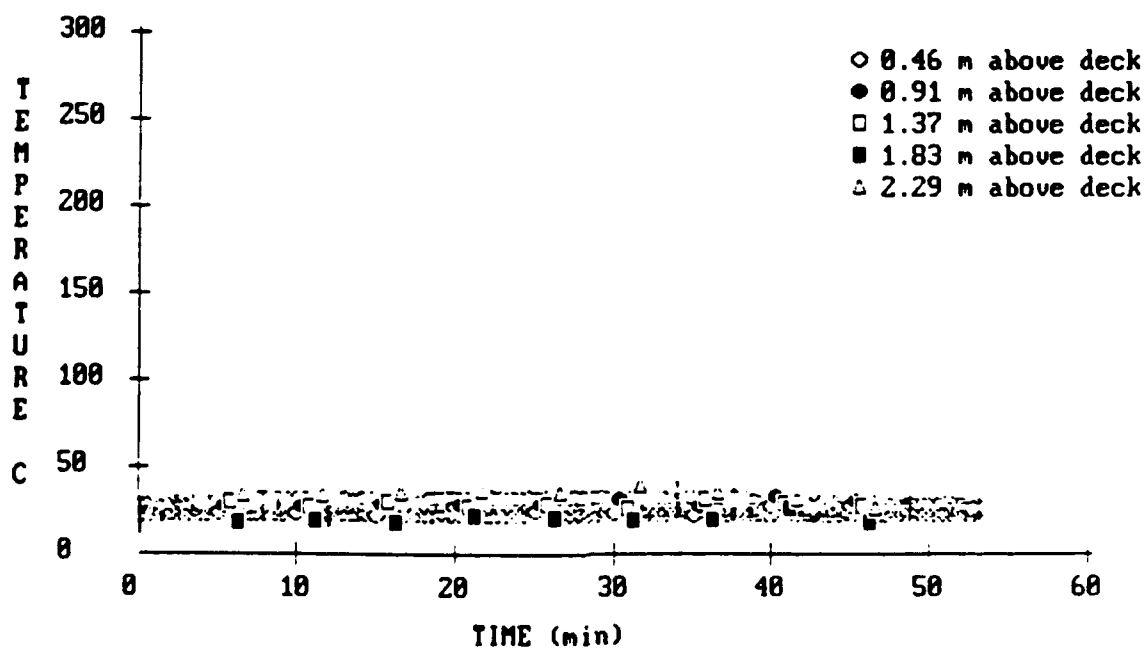


Fig. B-561- Temperature in RICER 1 (2-76-2) during Test # 16

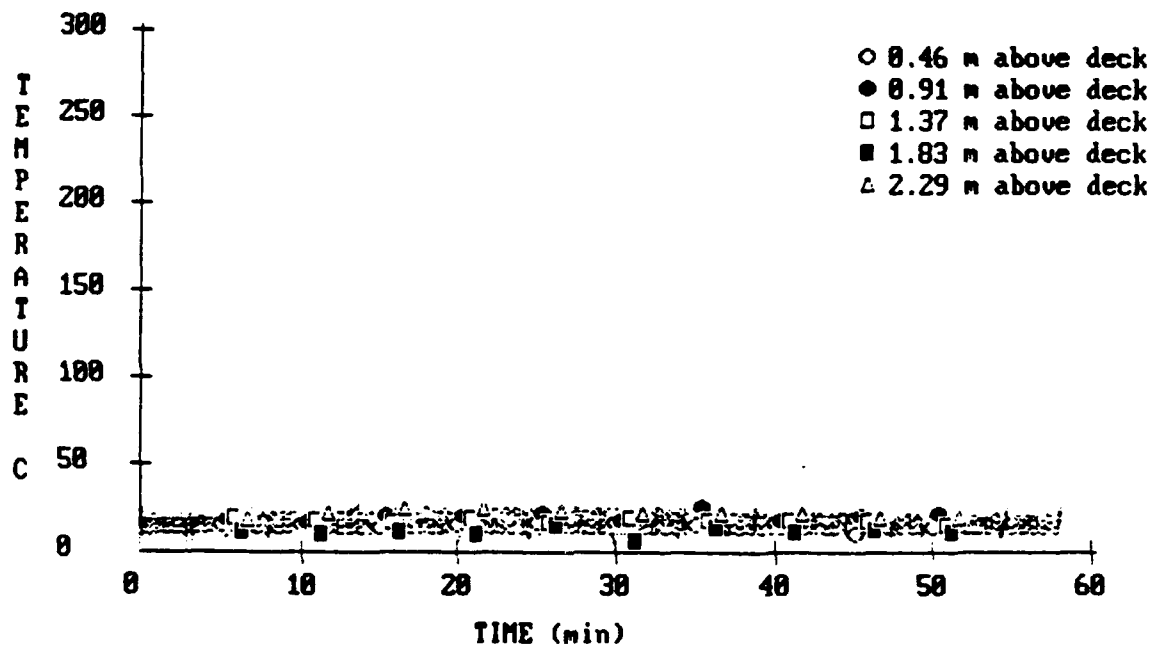


Fig. B-562- Temperature in RICER 1 (2-76-2) during Test # 17

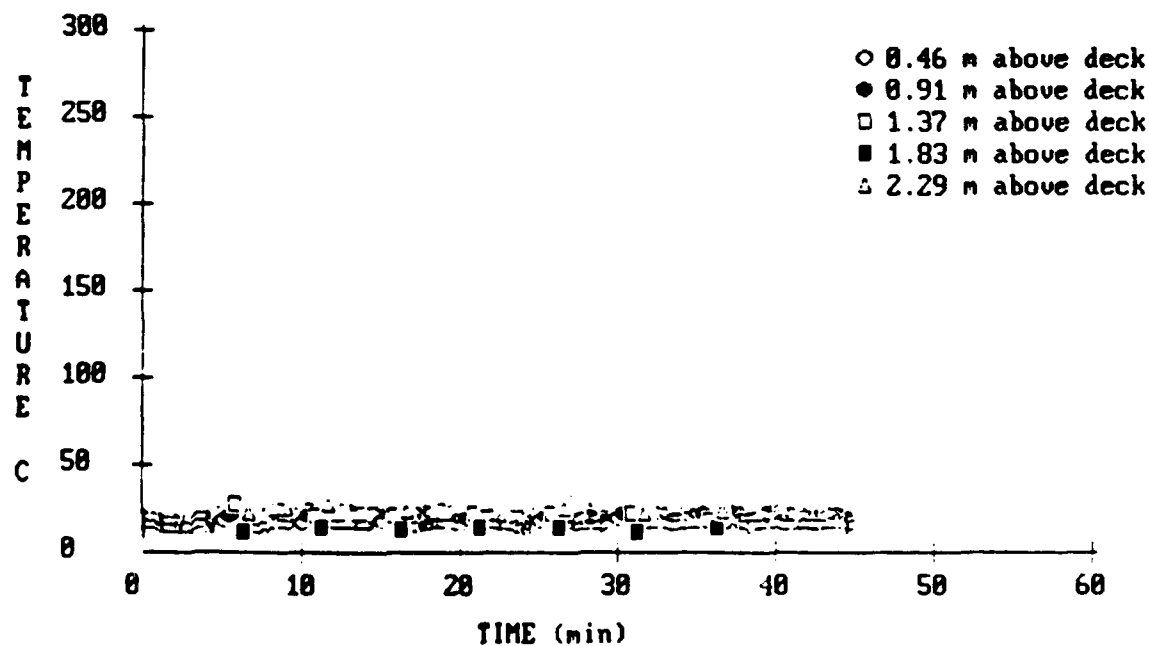


Fig. B-563- Temperature in RICER 1 (2-76-2) during Test # 18

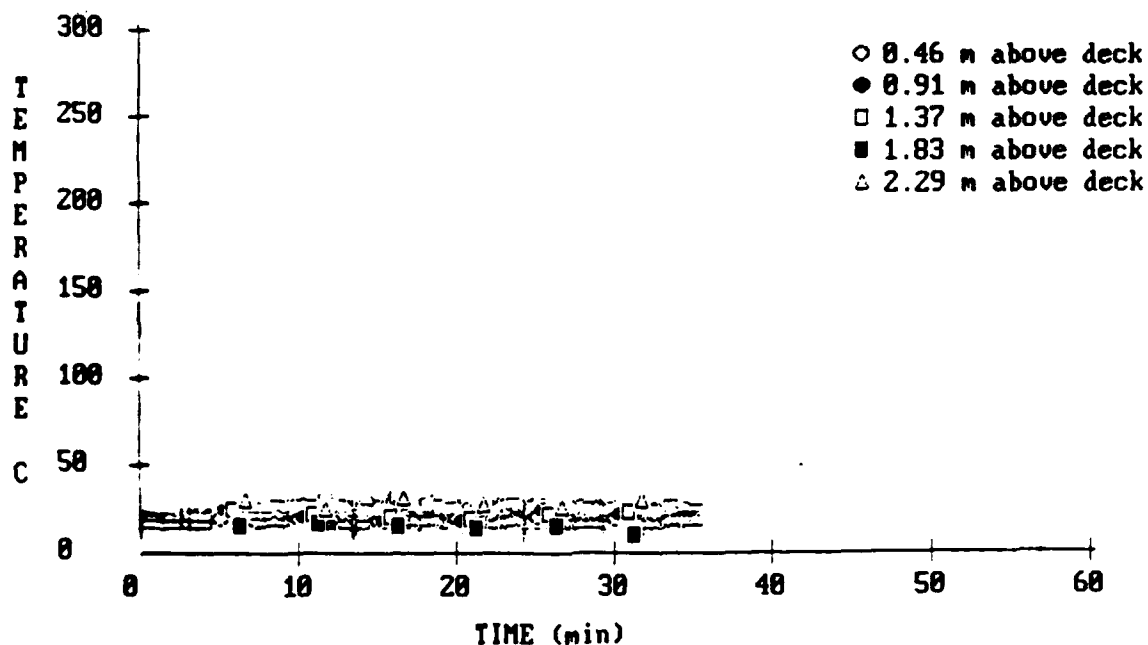


Fig. B-564- Temperature in RICER 1 (2-76-2) during Test # 19

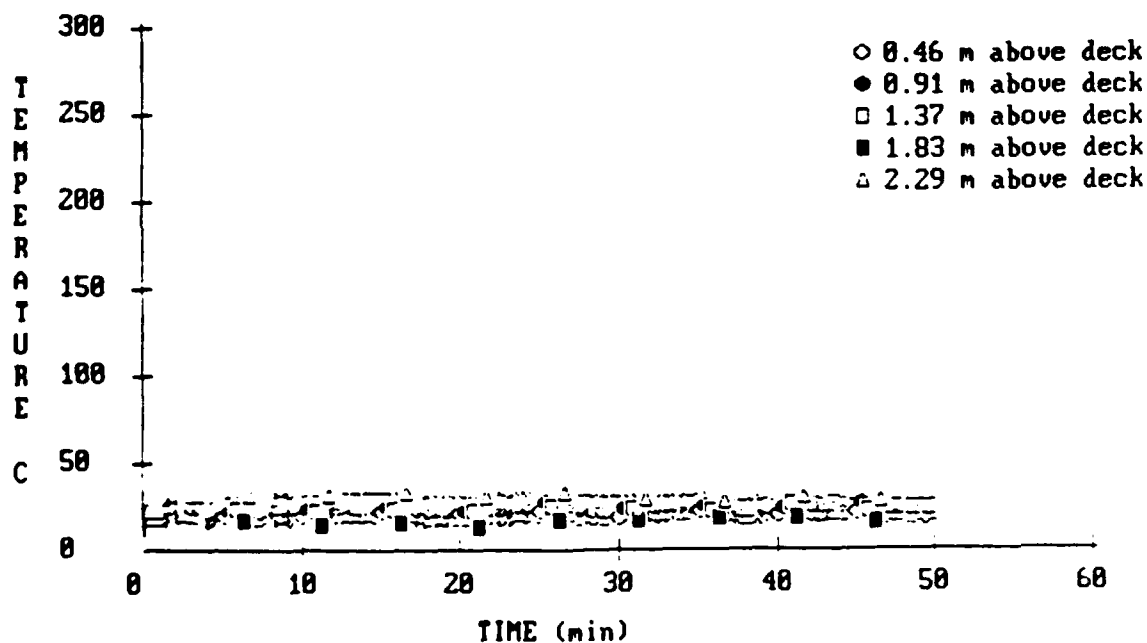


Fig. B-565- Temperature in RICER 1 (2-76-2) during Test # 20



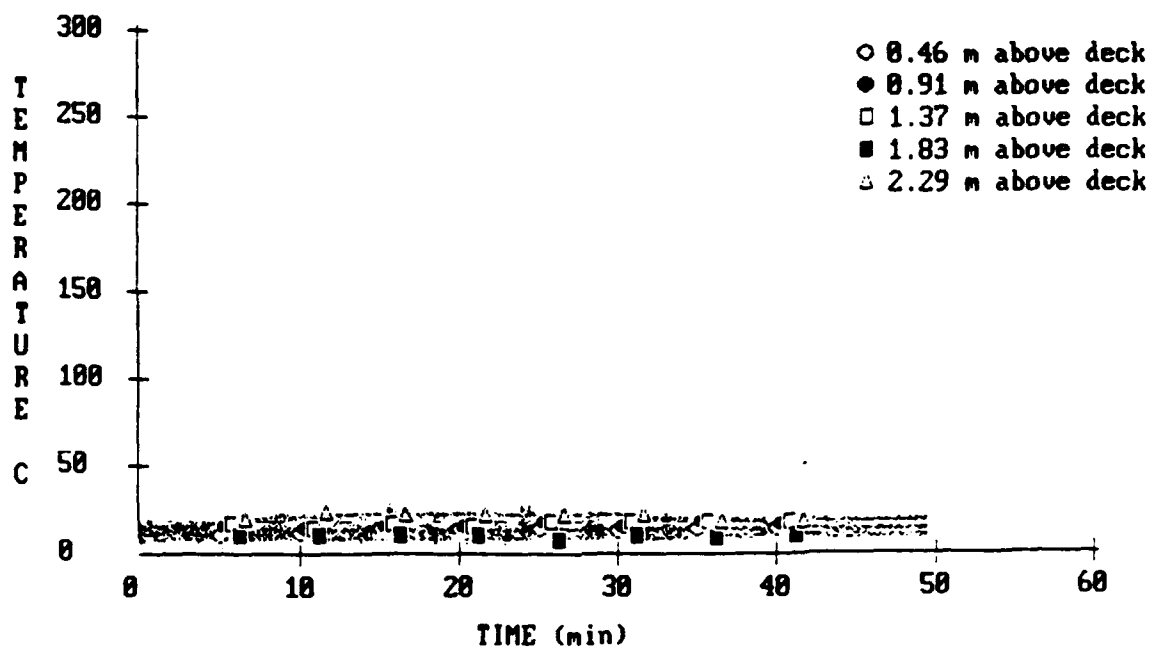


Fig. B-566- Temperature in RICER 1 (2-76-2) during Test # 21

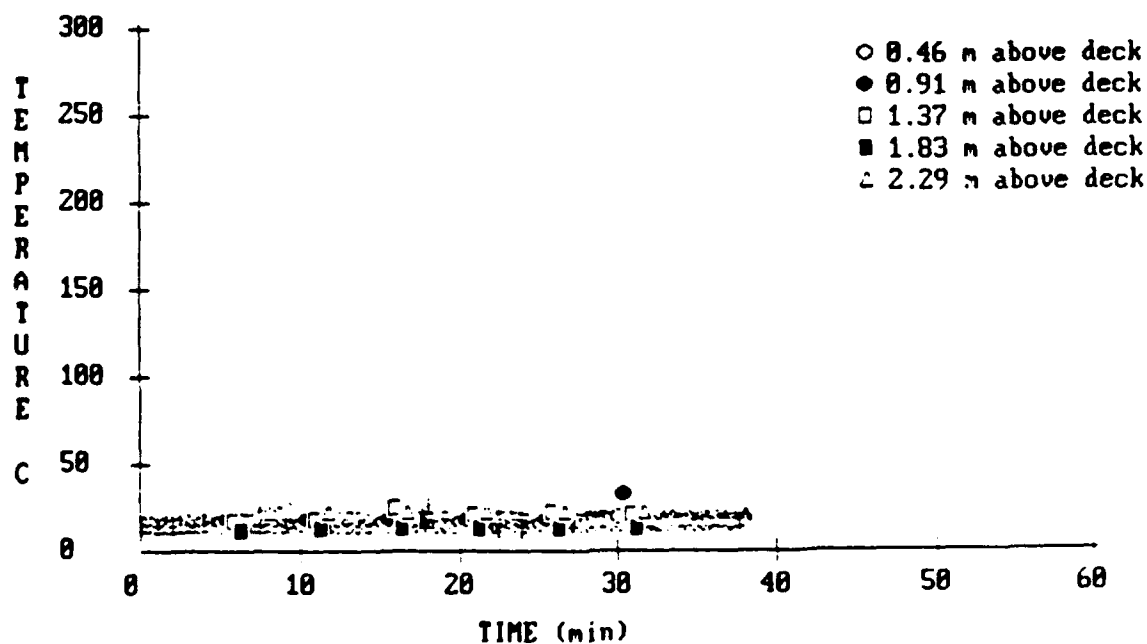


Fig. B-567- Temperature in RICER 1 (2-76-2) during Test # 22

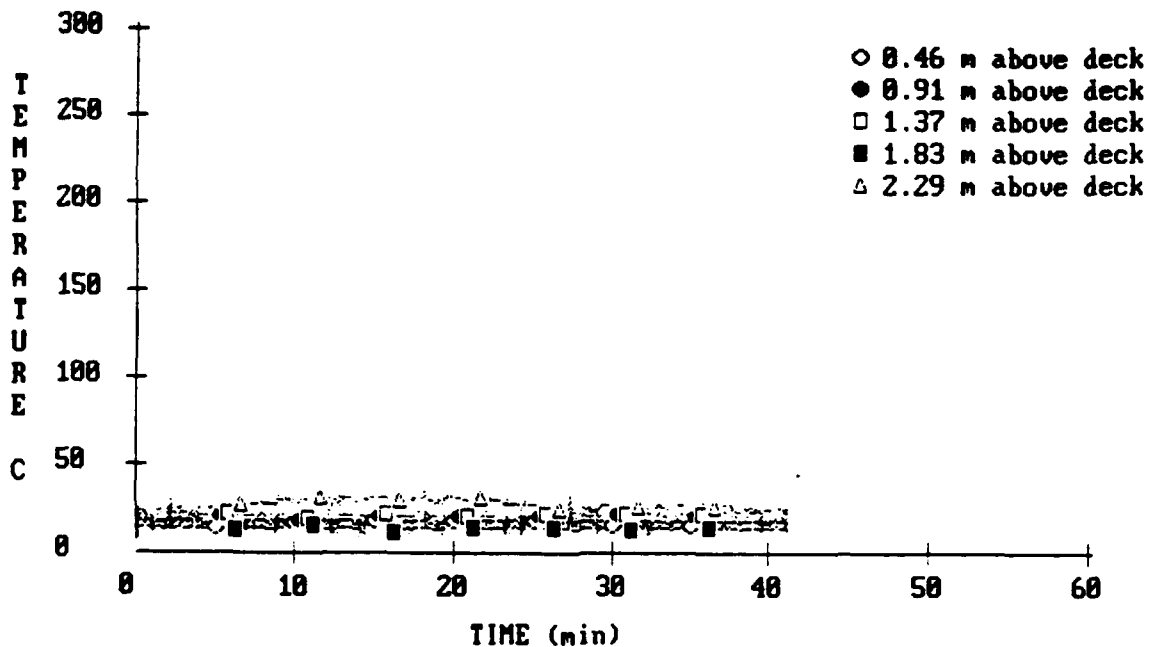


Fig. B-568- Temperature in RICER 1 (2-76-2) during Test # 23

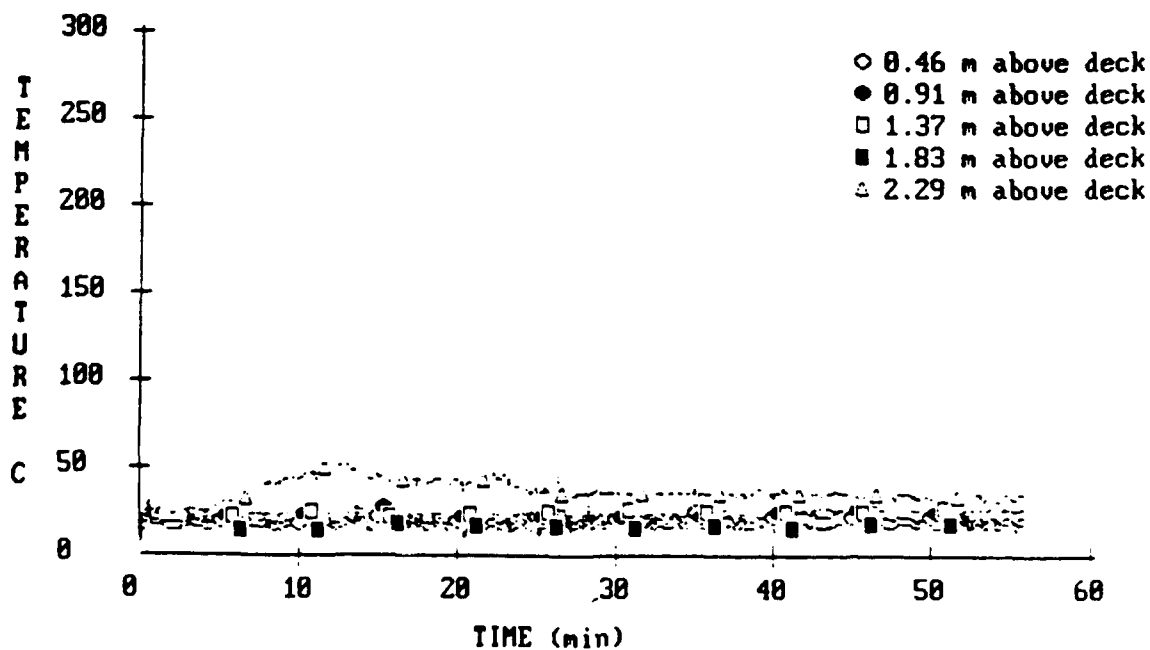


Fig. B-569- Temperature in RICER 1 (2-76-2) during Test # 24

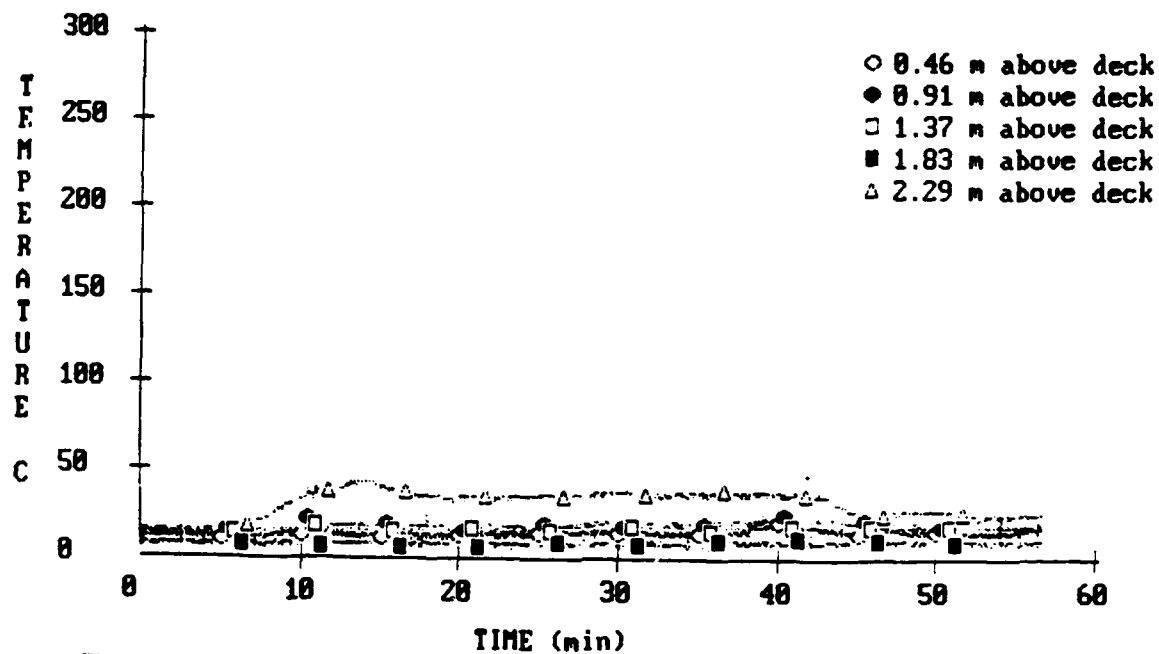


Fig. B-570- Temperature in RICER 1 (2-76-2) during Test # 25

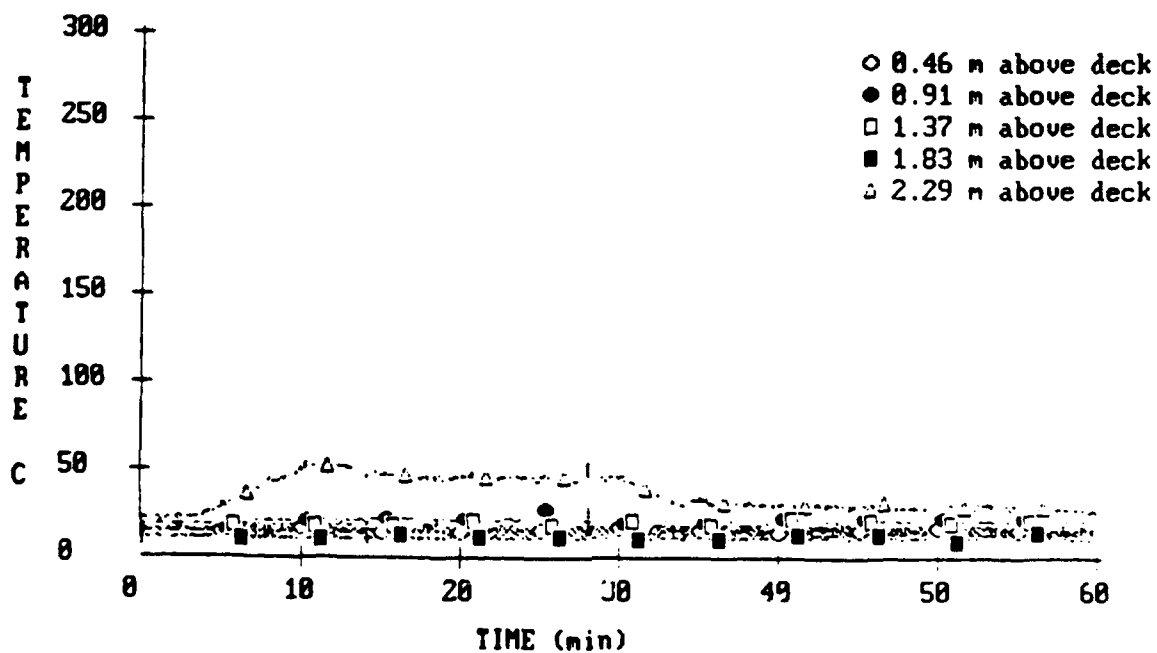


Fig. B-571- Temperature in RICER 1 (2-76-2) during Test # 26

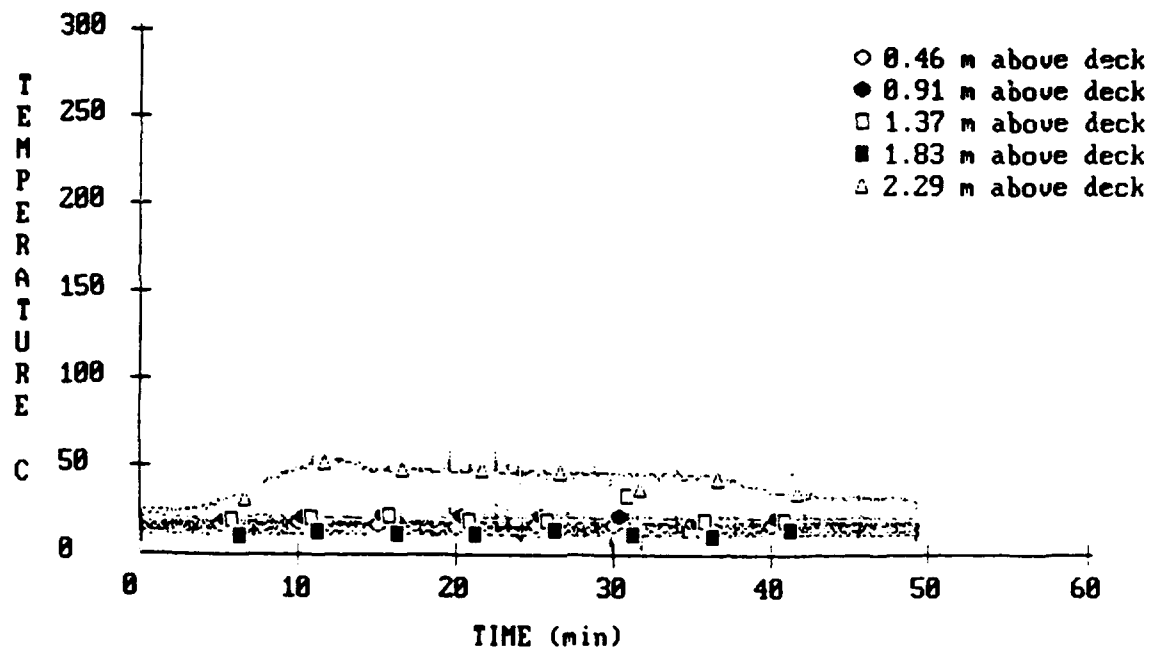


Fig. B-572- Temperature in RICER 1 (2-76-2) during Test # 27

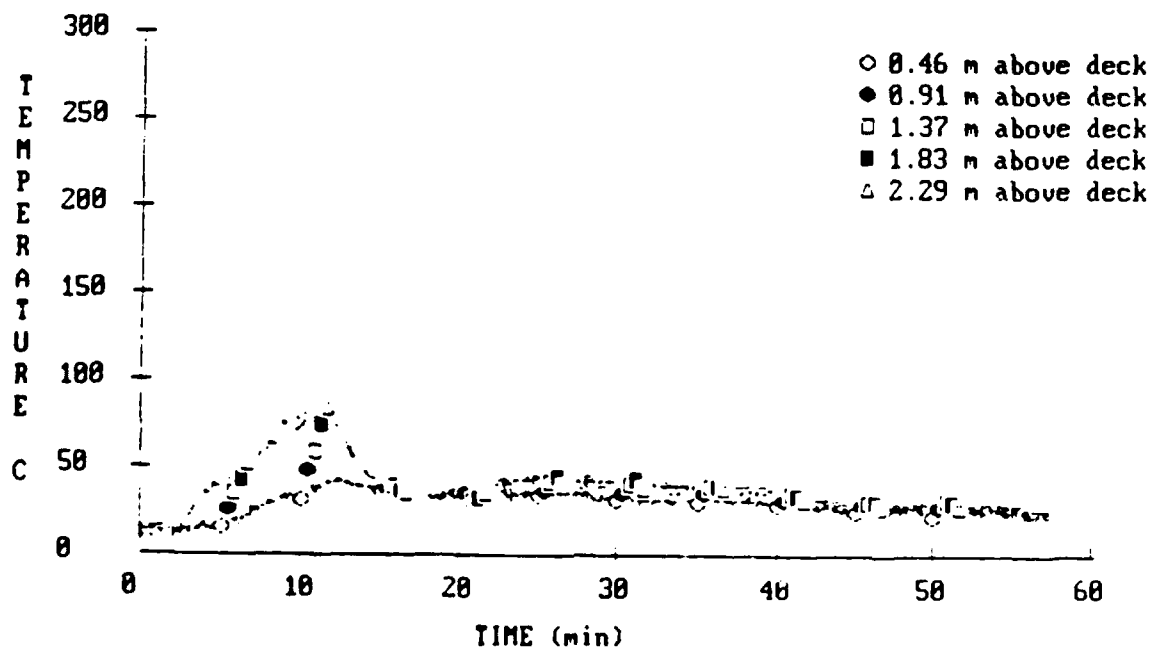


Fig. B-573- Temperature in RICER 1 (2-76-2) during Test # 28

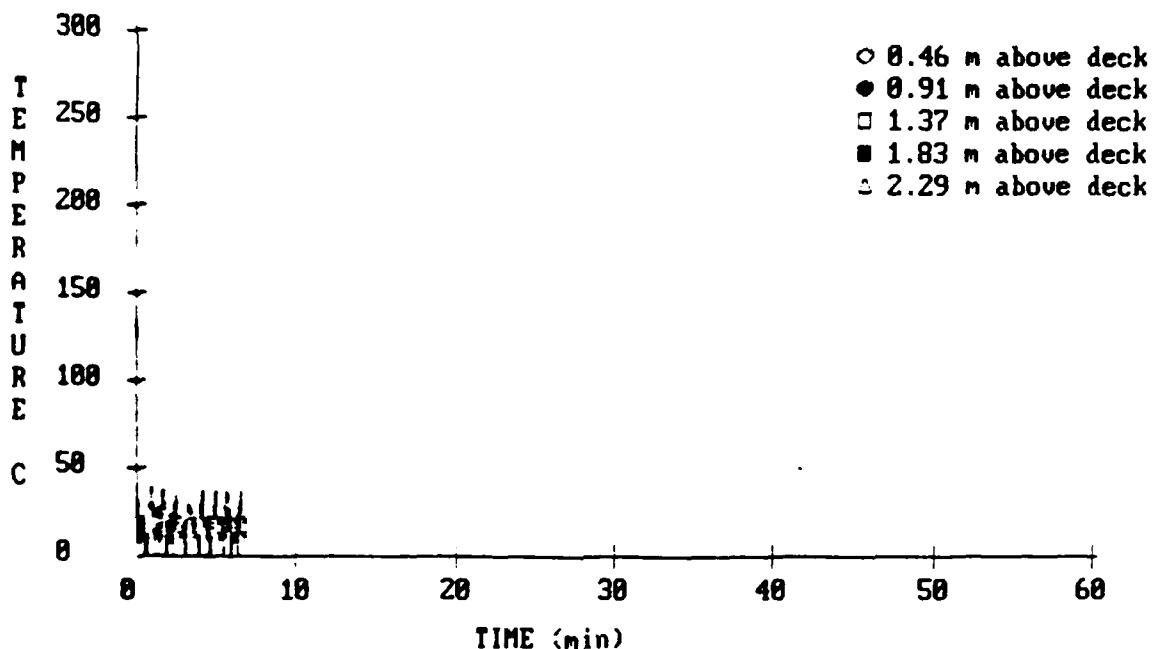


Fig. B-574- Temperature in RICER 1 (2-76-2) during Test # 29

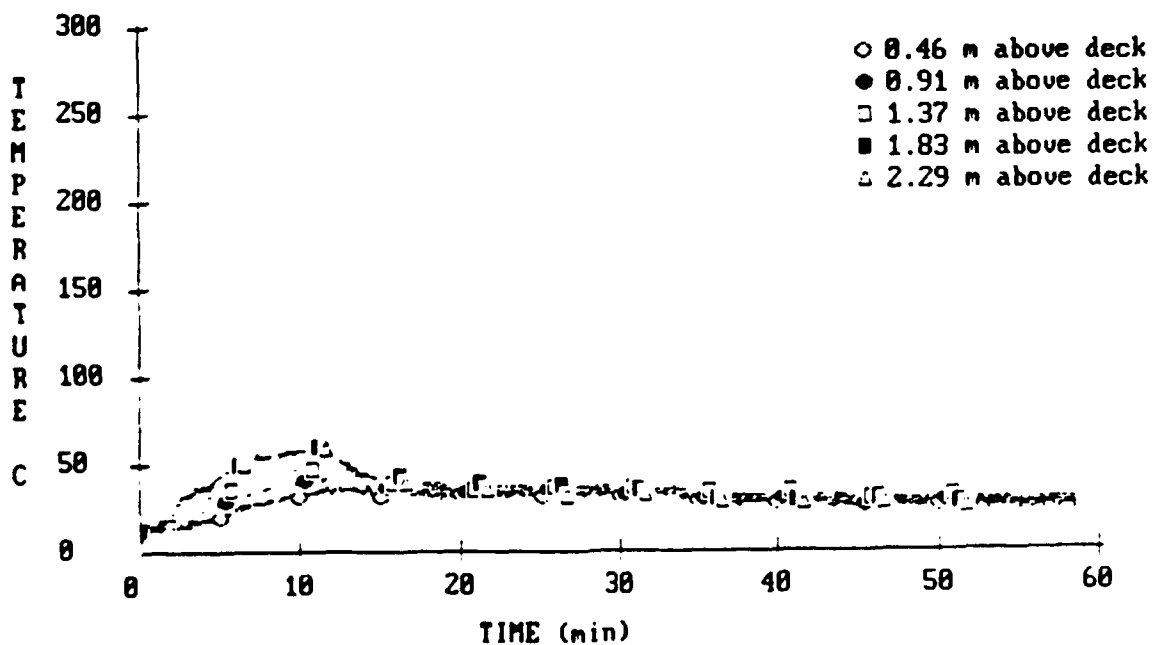


Fig. B-575- Temperature in RICER 1 (2-76-2) during Test # 30

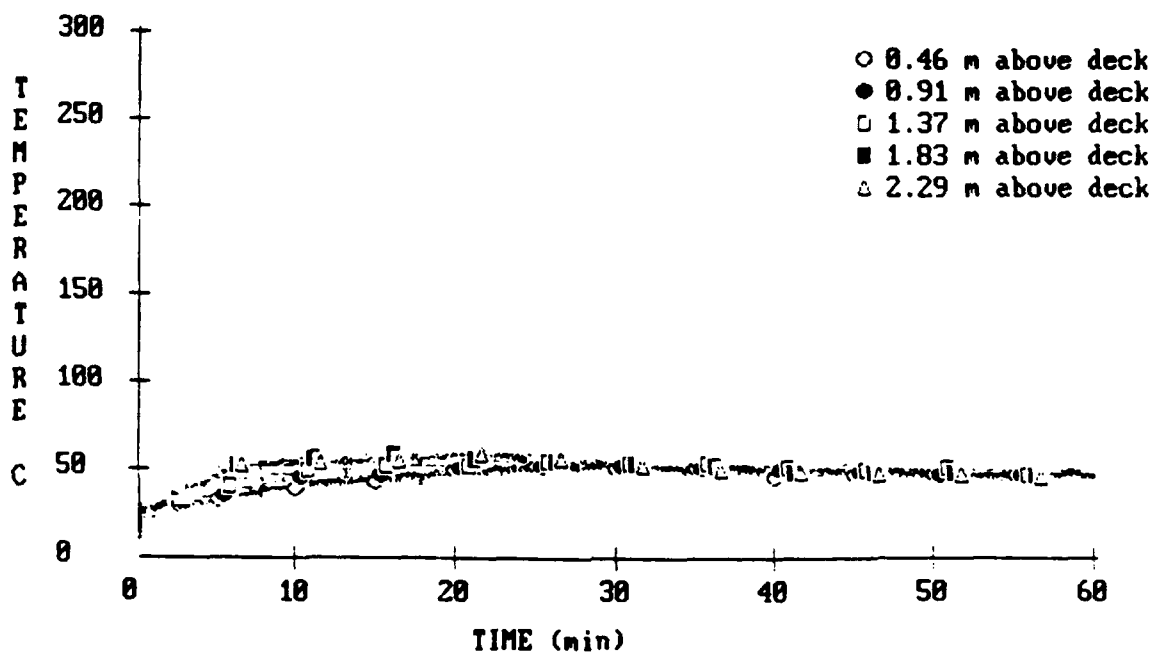


Fig. B-576- Temperature in RICER 1 (2-76-2) during Test # 31

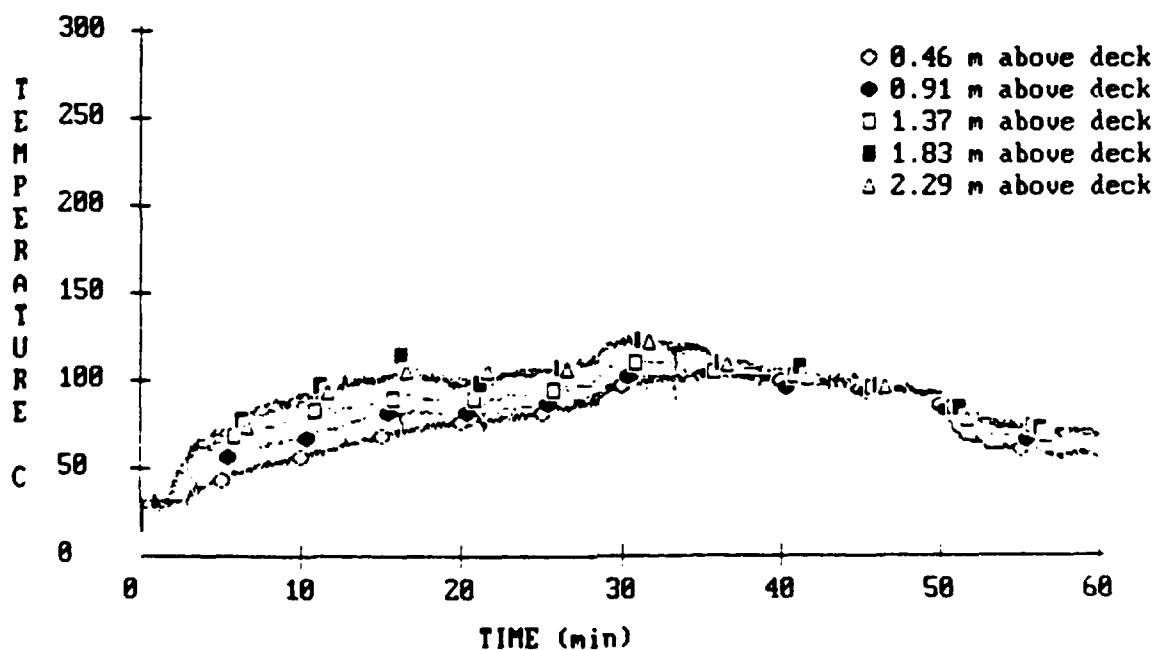


Fig. B-577- Temperature in RICER 1 (2-76-2) during Test # 32

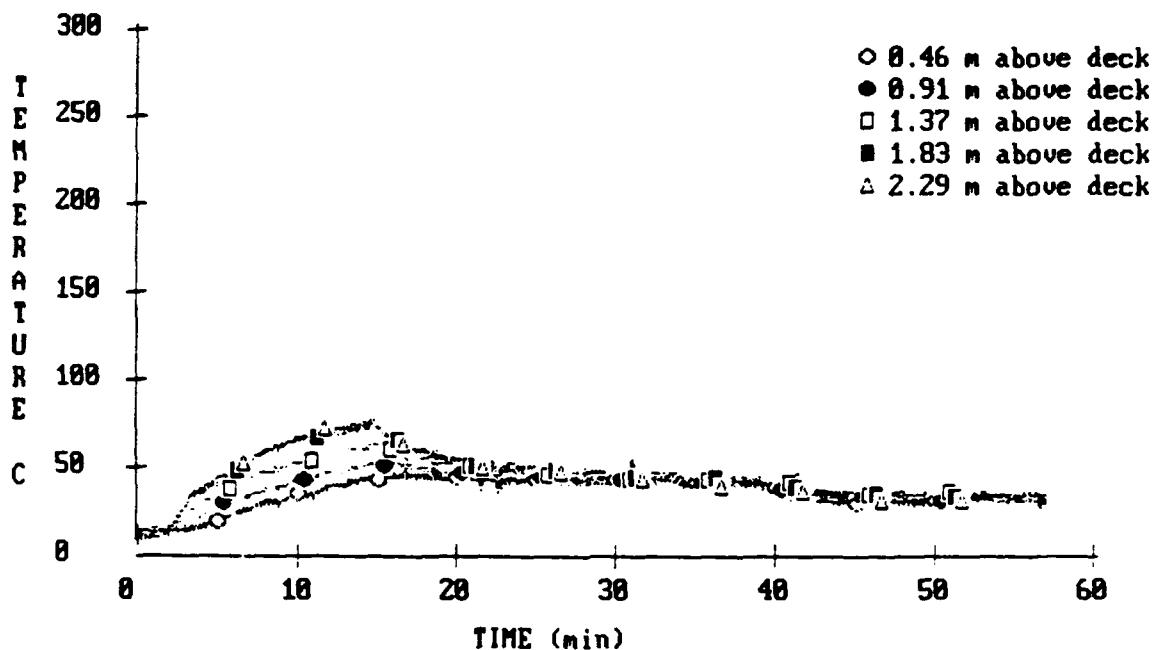


Fig. B-578- Temperature in RICER 1 (2-76-2) during Test # 33

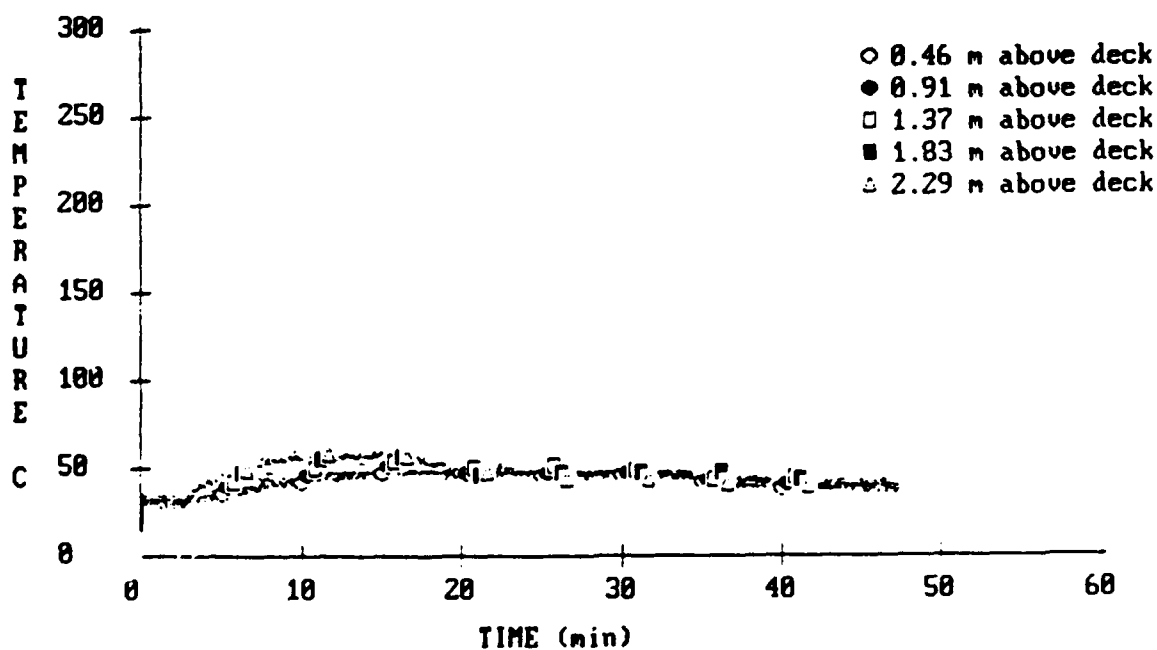


Fig. B-579- Temperature in RICER 1 (2-76-2) during Test # 34

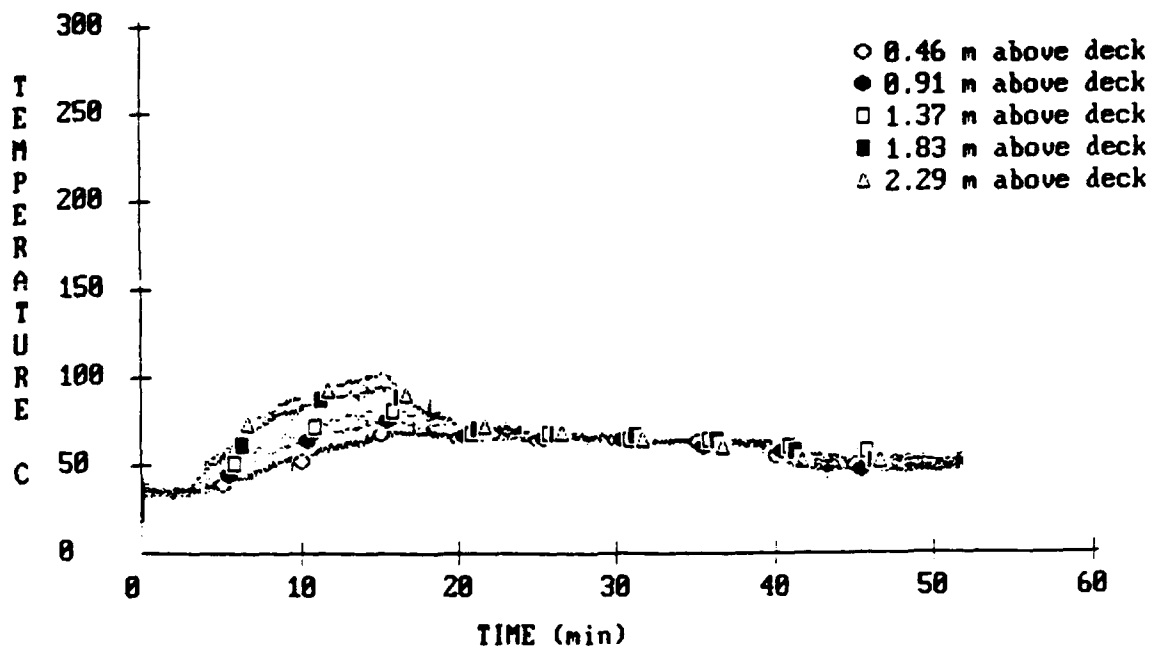


Fig. B-580- Temperature in RICER 1 (2-76-2) during Test # 35

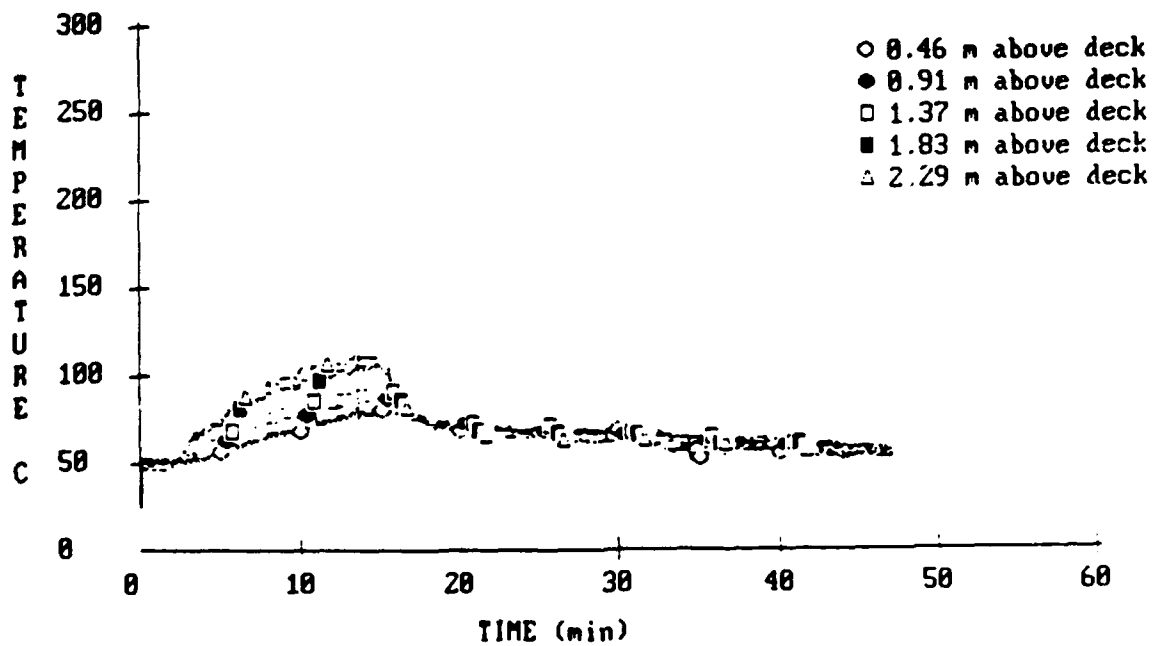


Fig. B-581- Temperature in RICER 1 (2-76-2) during Test # 36



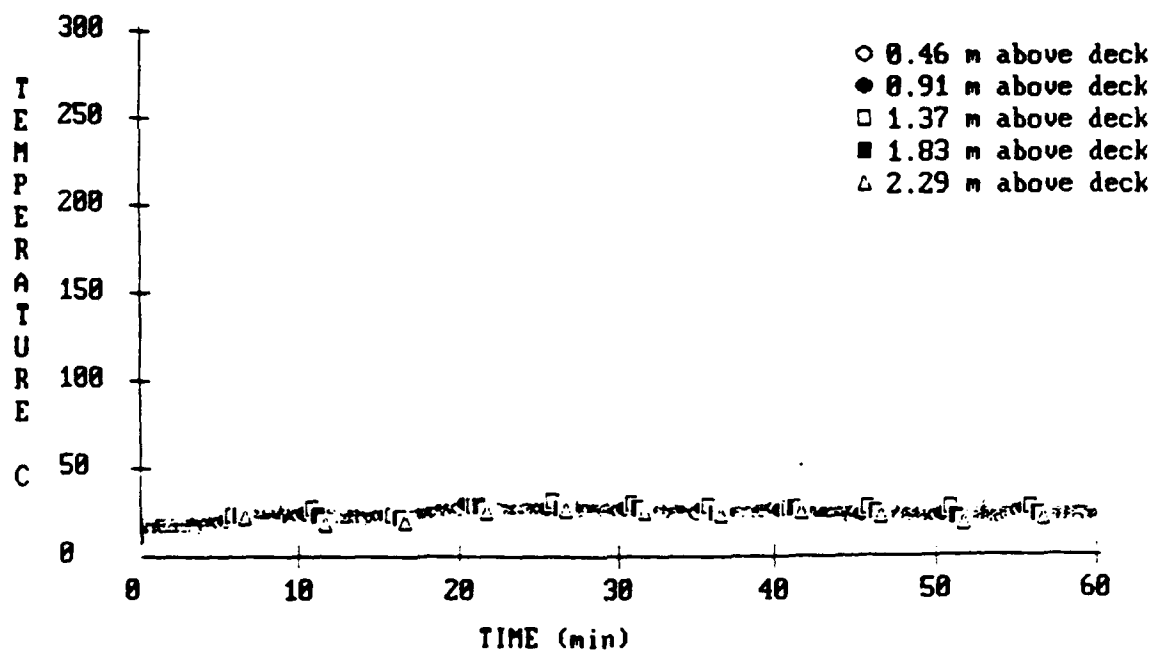


Fig. B-582- Temperature in RICER 1 (2-76-2) during Test # 37

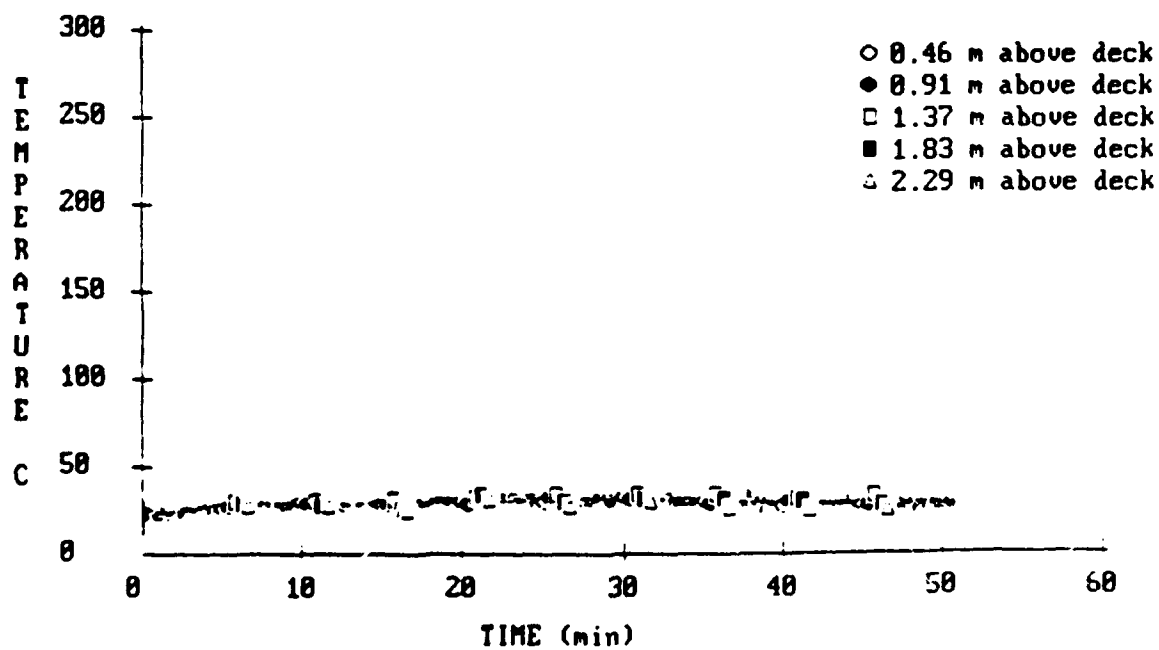


Fig. B-583- Temperature in RICER 1 (2-76-2) during Test # 38

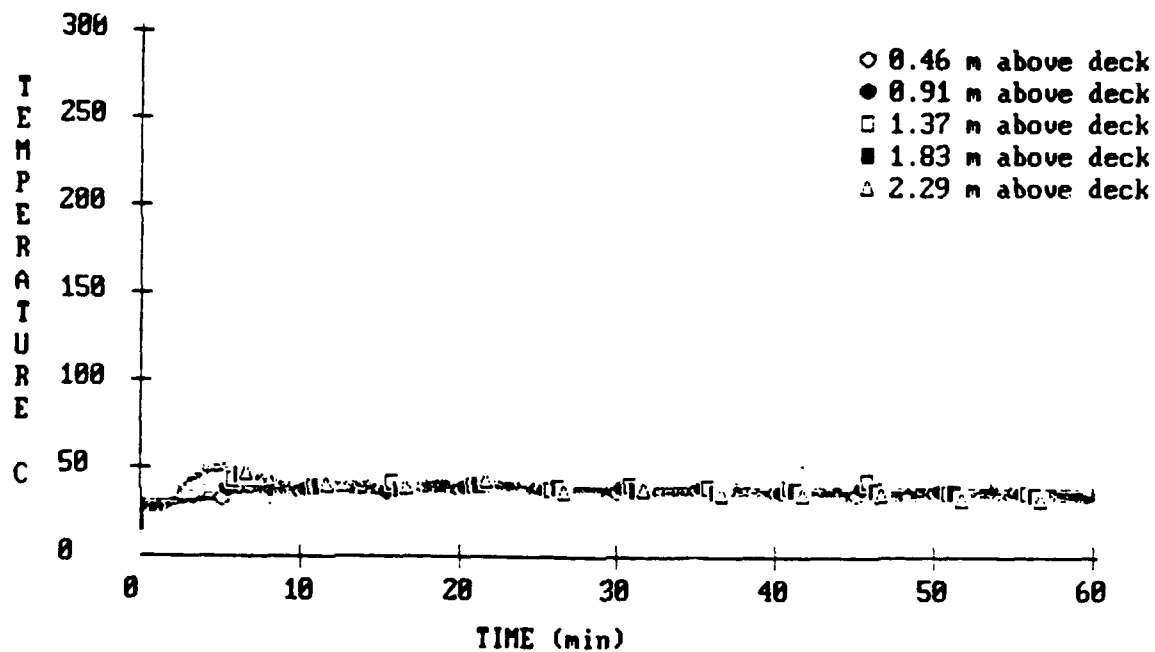


Fig. B-584- Temperature in RICER 1 (2-76-2) during Test # 39

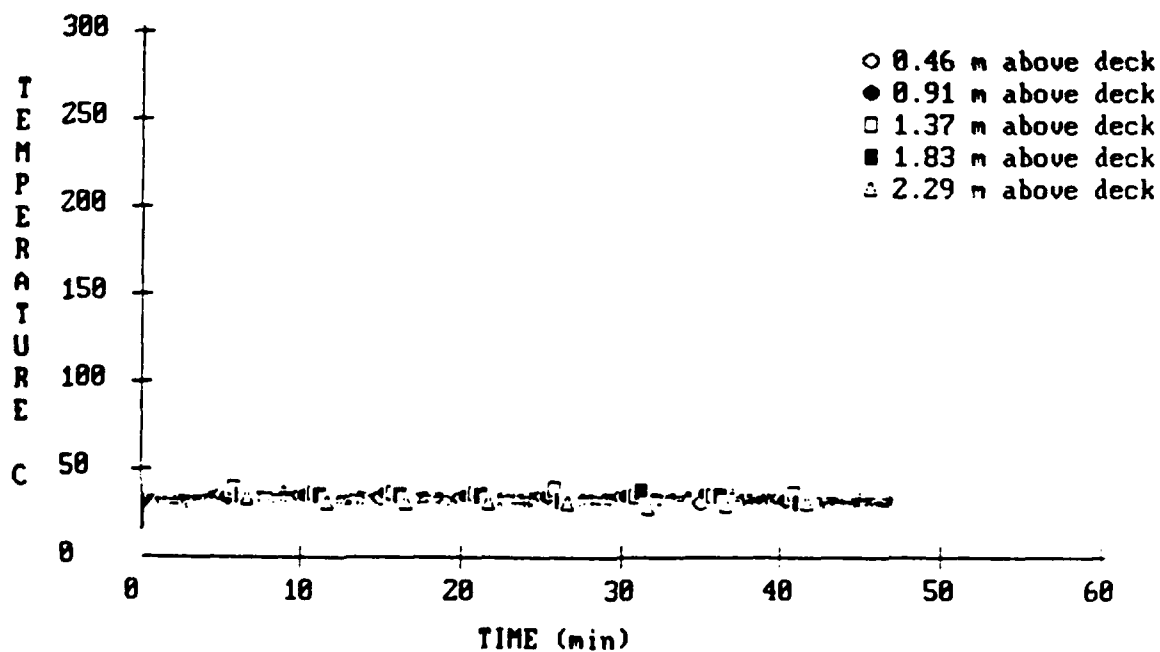


Fig. B-585- Temperature in RICER 1 (2-76-2) during Test # 40

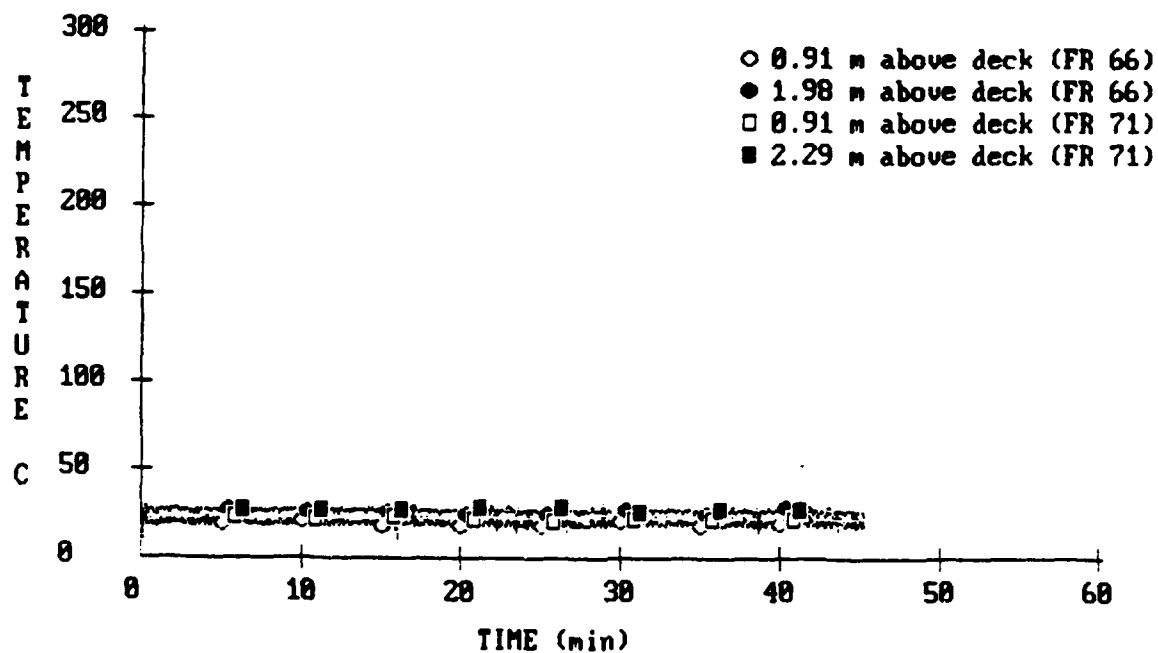


Fig. B-586- Temperature in the forward compartment during Test # 2

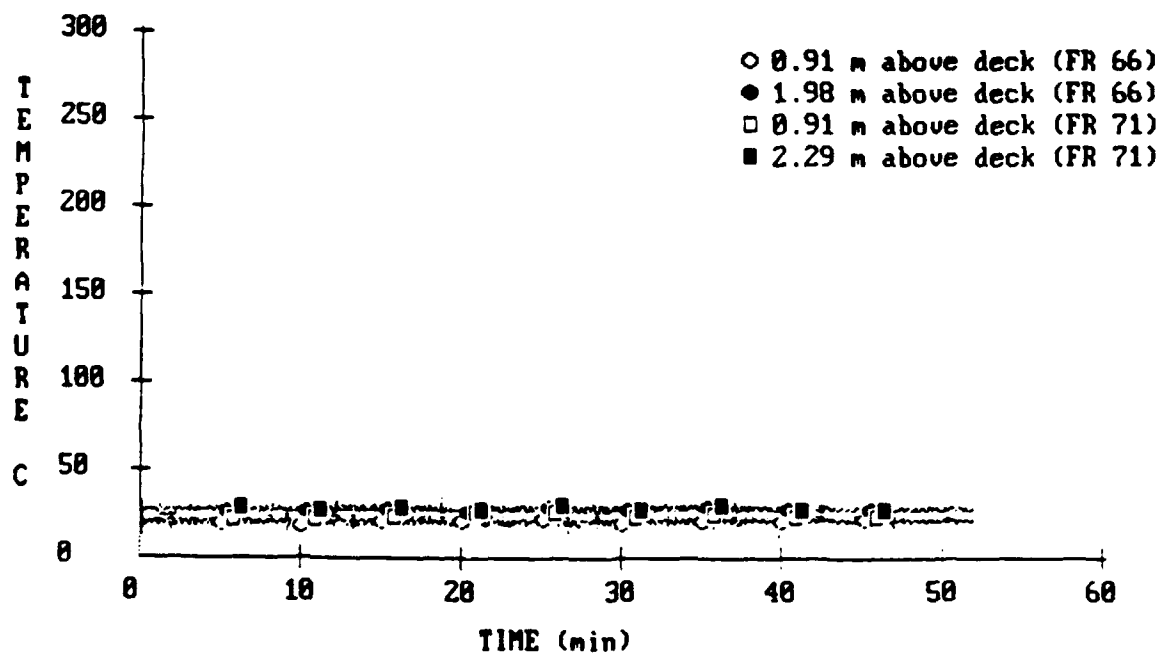


Fig. B-587- Temperature in the forward compartment during Test # 3

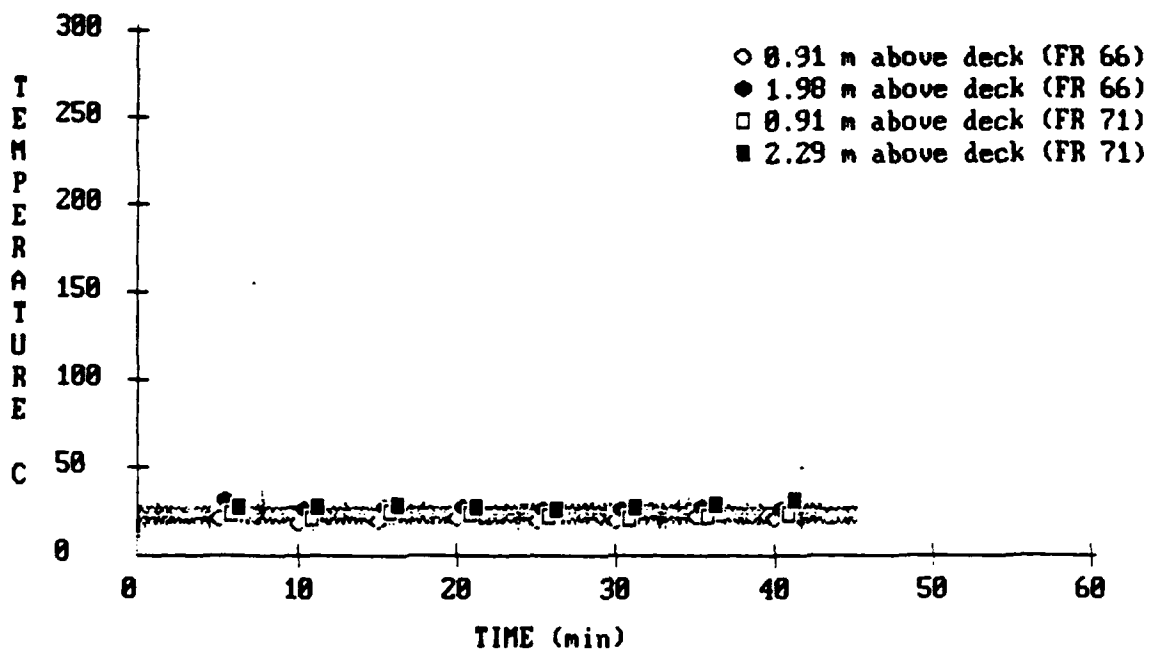


Fig. B-588- Temperature in the forward compartment during Test # 4

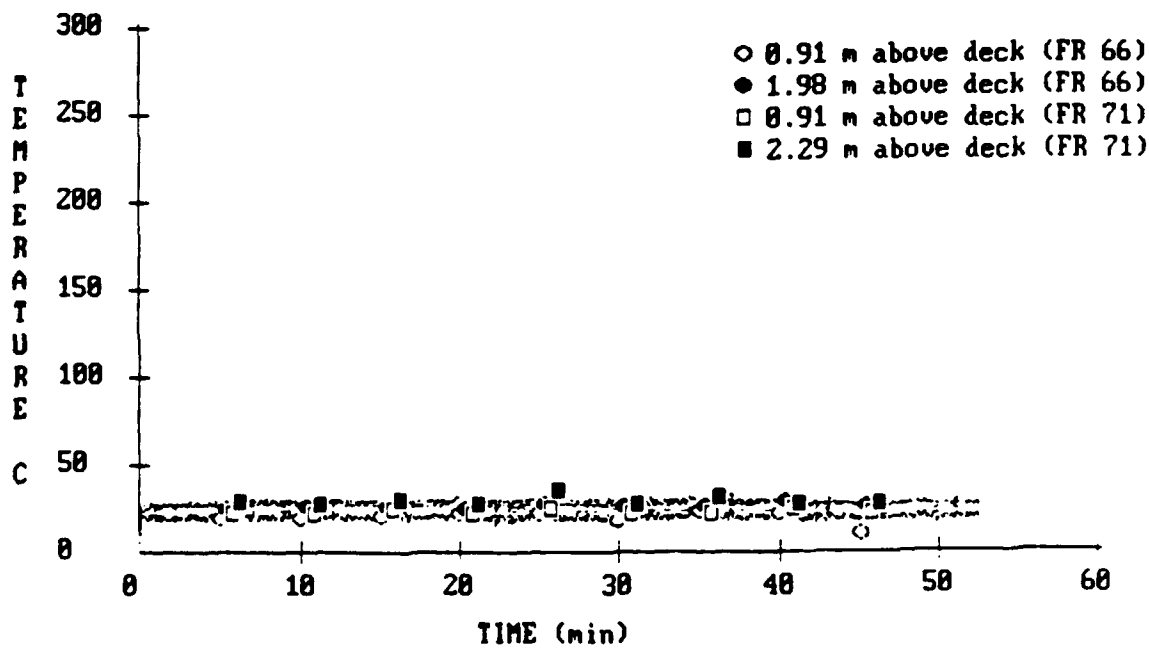


Fig. B-589- Temperature in the forward compartment during Test # 5

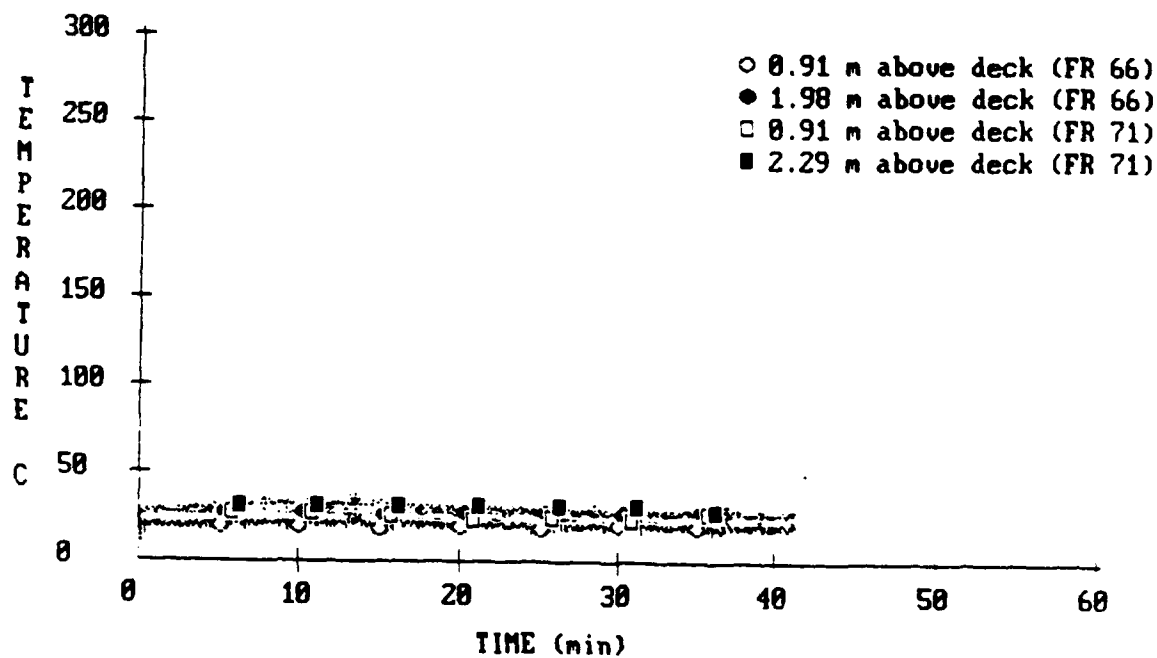


Fig. B-590- Temperature in the forward compartment during Test # 6

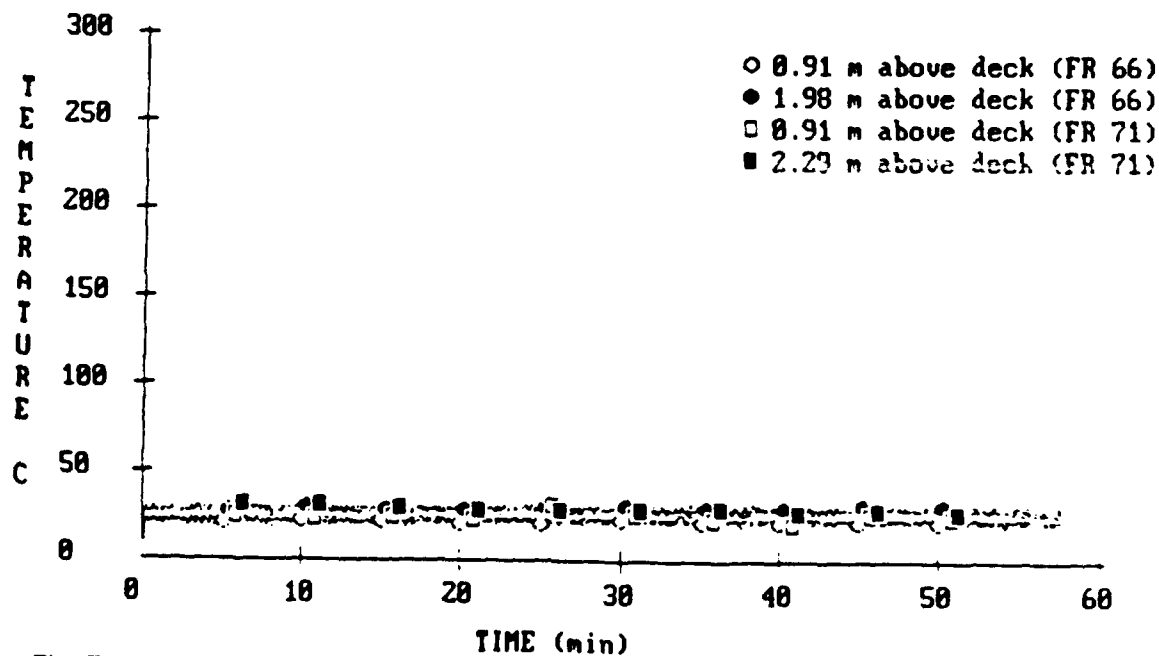


Fig. B-591- Temperature in the forward compartment during Test # 7

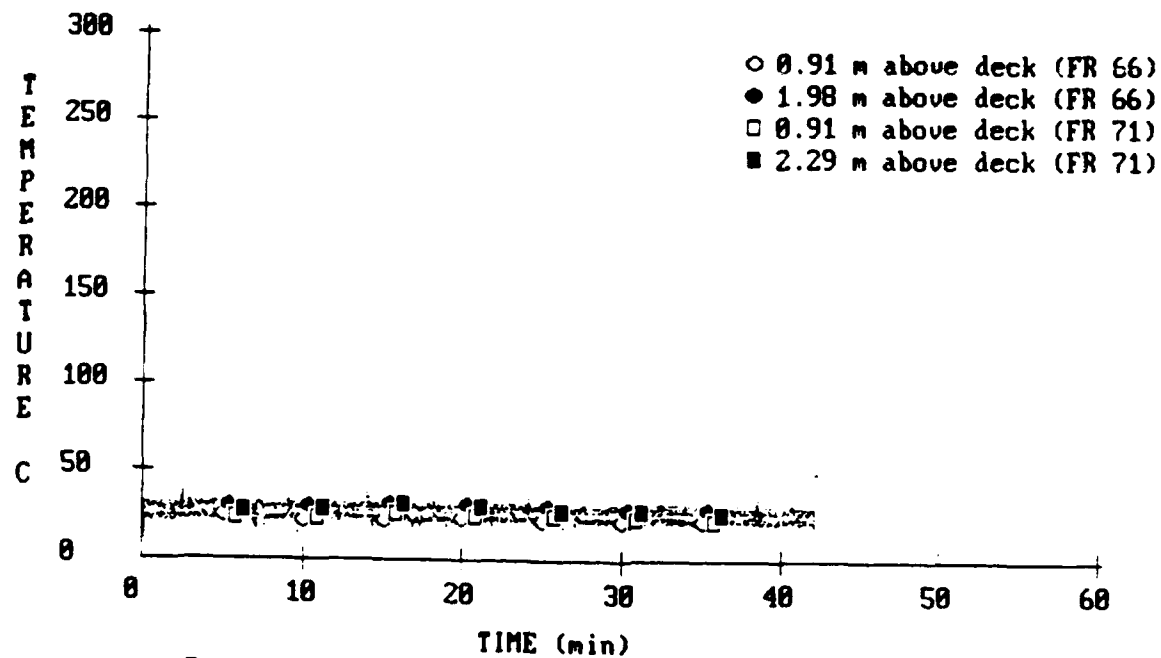


Fig. B-592- Temperature in the forward compartment during Test # 8

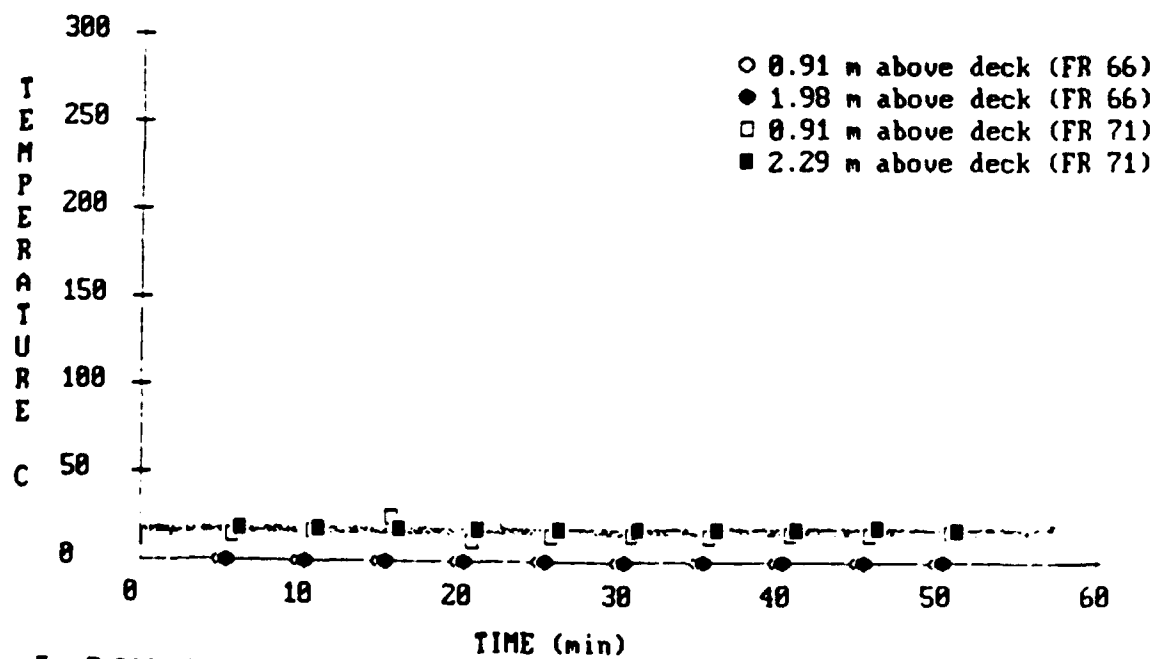


Fig. B-593- Temperature in the forward compartment during Test # 9

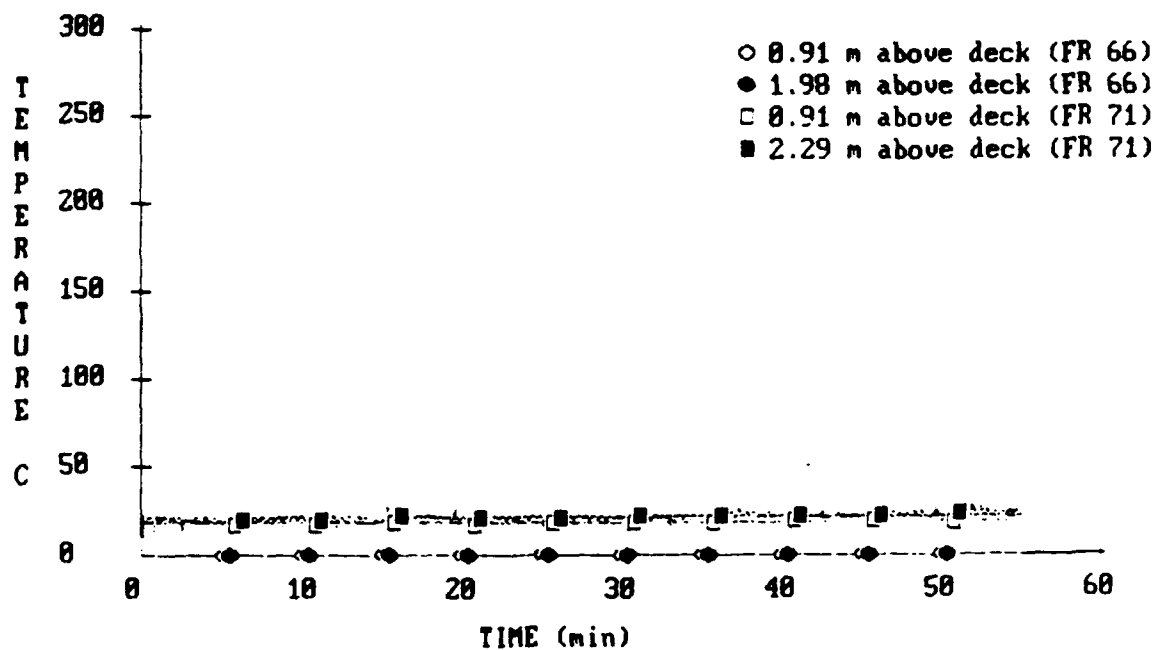


Fig. B-594- Temperature in the forward compartment during Test # 10

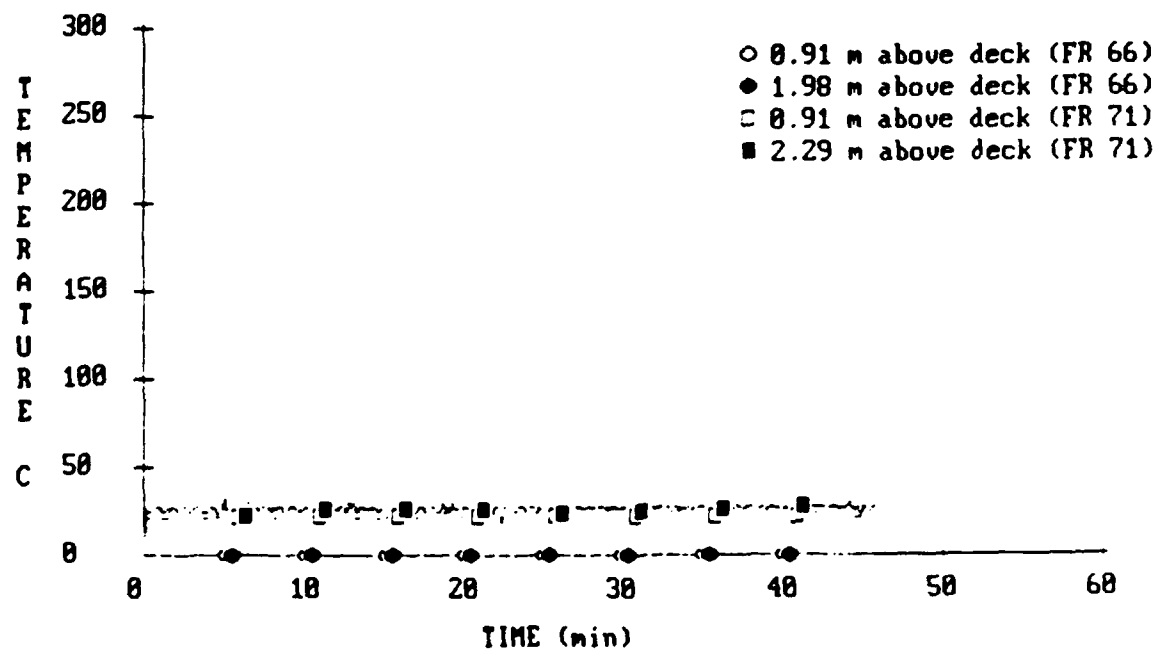


Fig. B-595- Temperature in the forward compartment during Test # 11

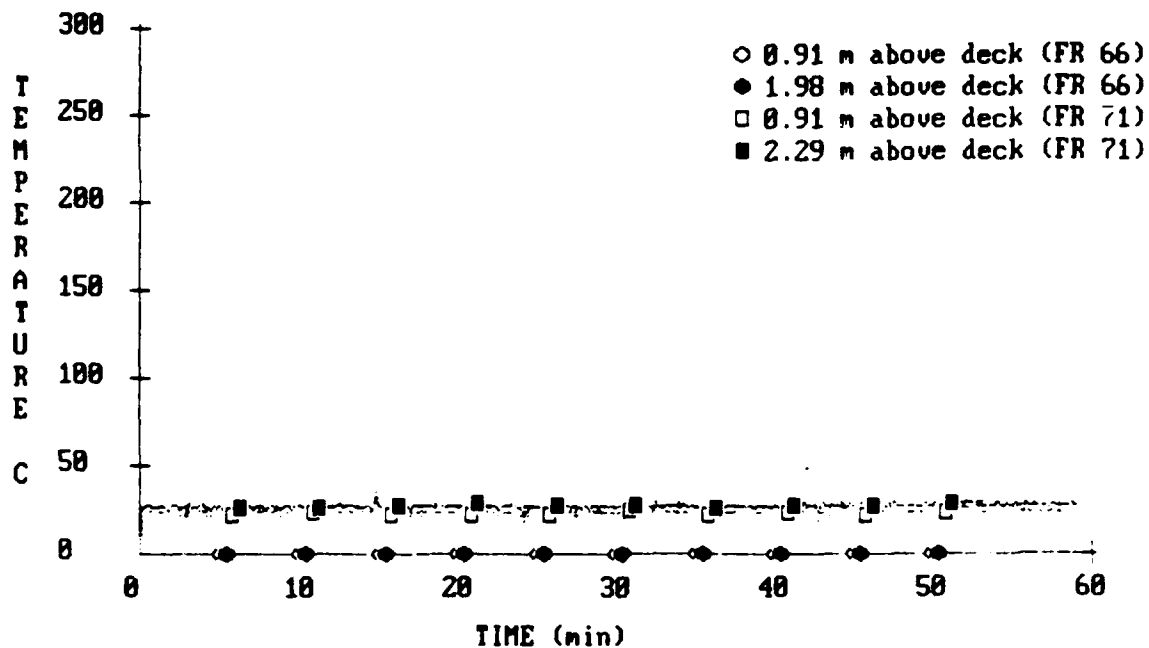


Fig. B 596- Temperature in the forward compartment during Test # 12

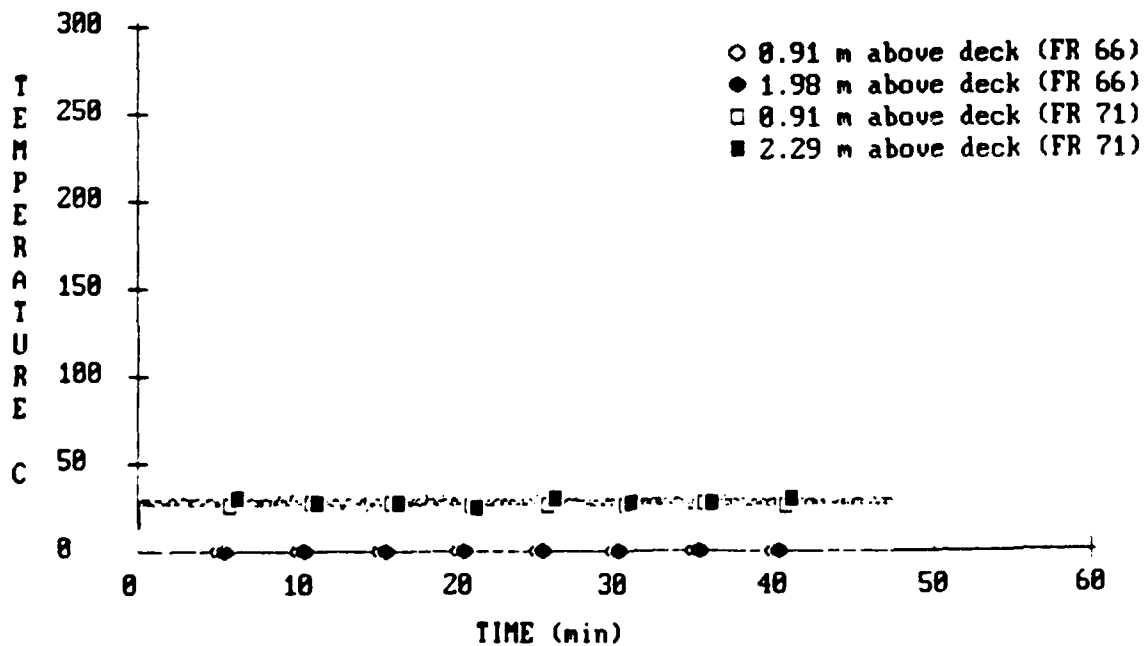


Fig. B-597- Temperature in the forward compartment during Test # 13



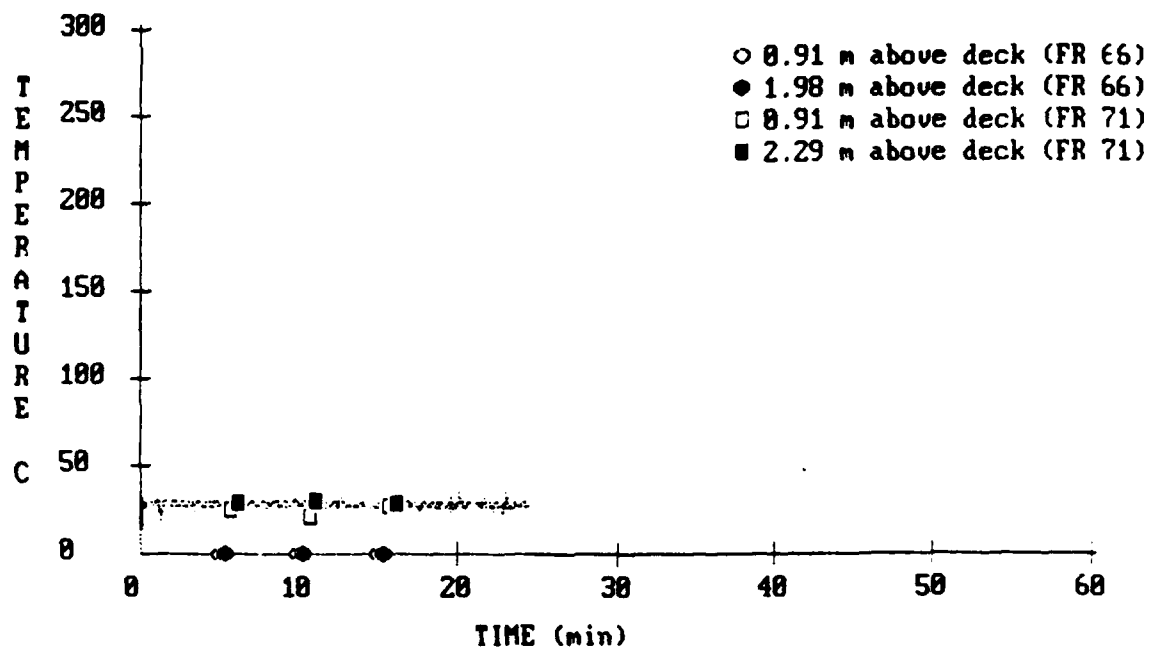


Fig. B-598- Temperature in the forward compartment during Test # 14

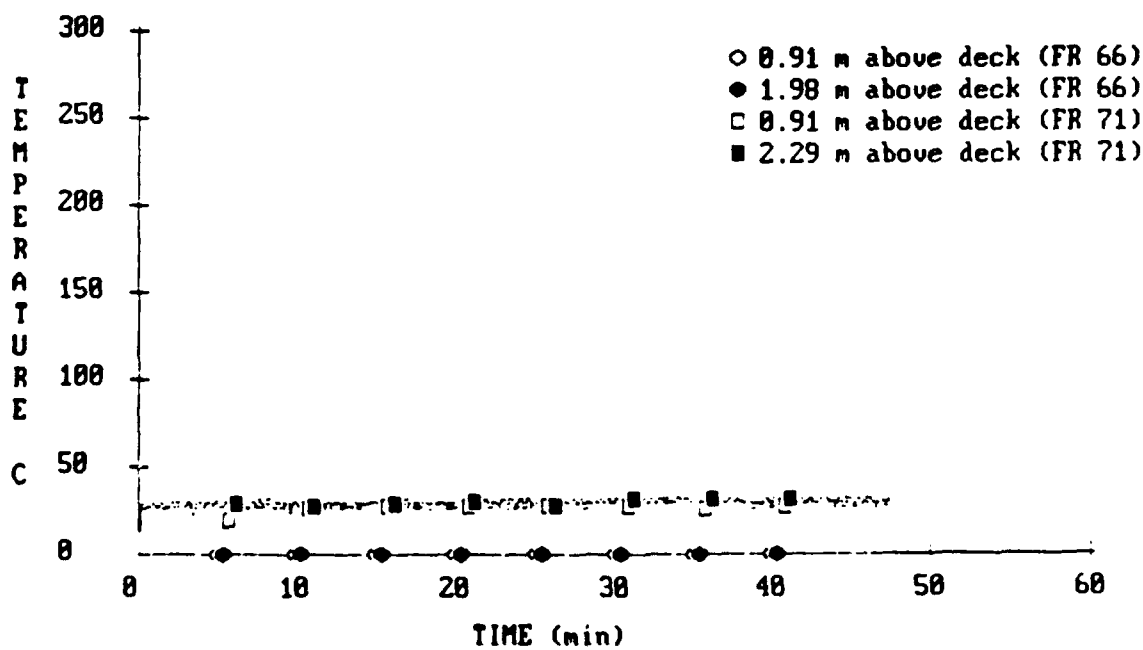


Fig. B-599- Temperature in the forward compartment during Test # 15

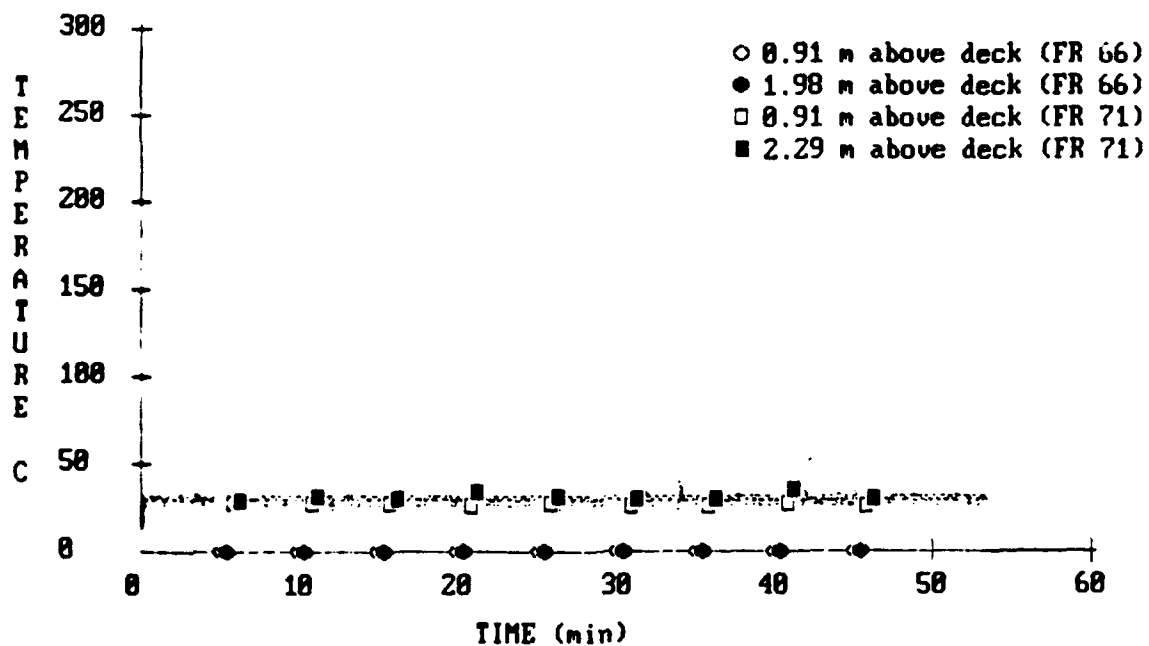


Fig. B-600- Temperature in the forward compartment during Test # 16

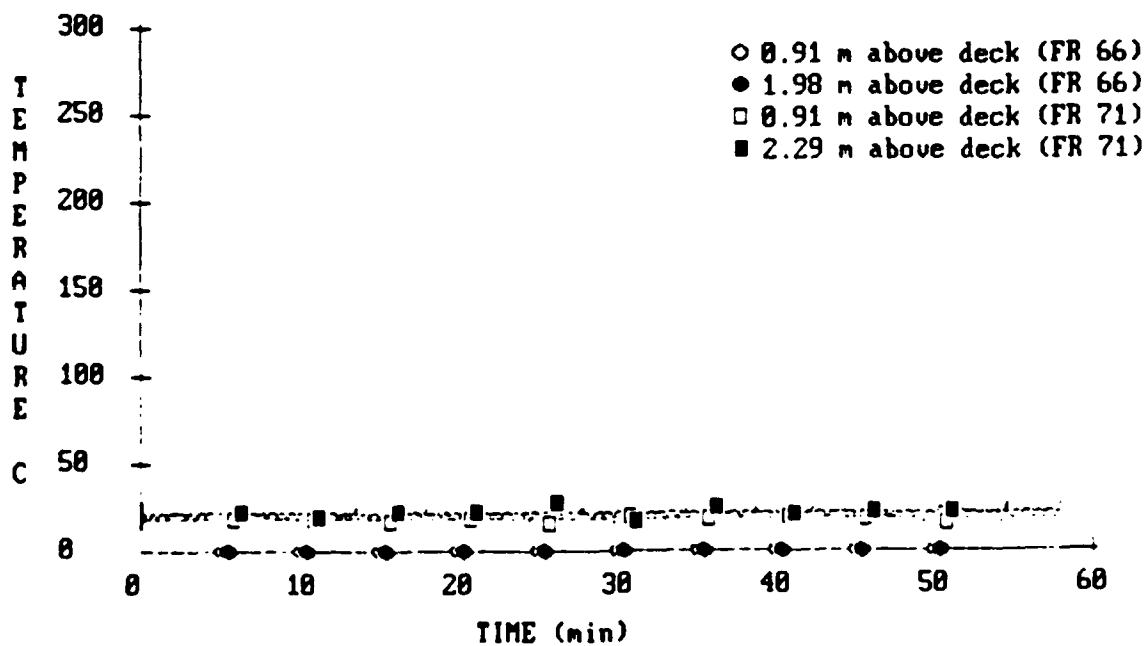


Fig. B-601- Temperature in the forward compartment during Test # 17

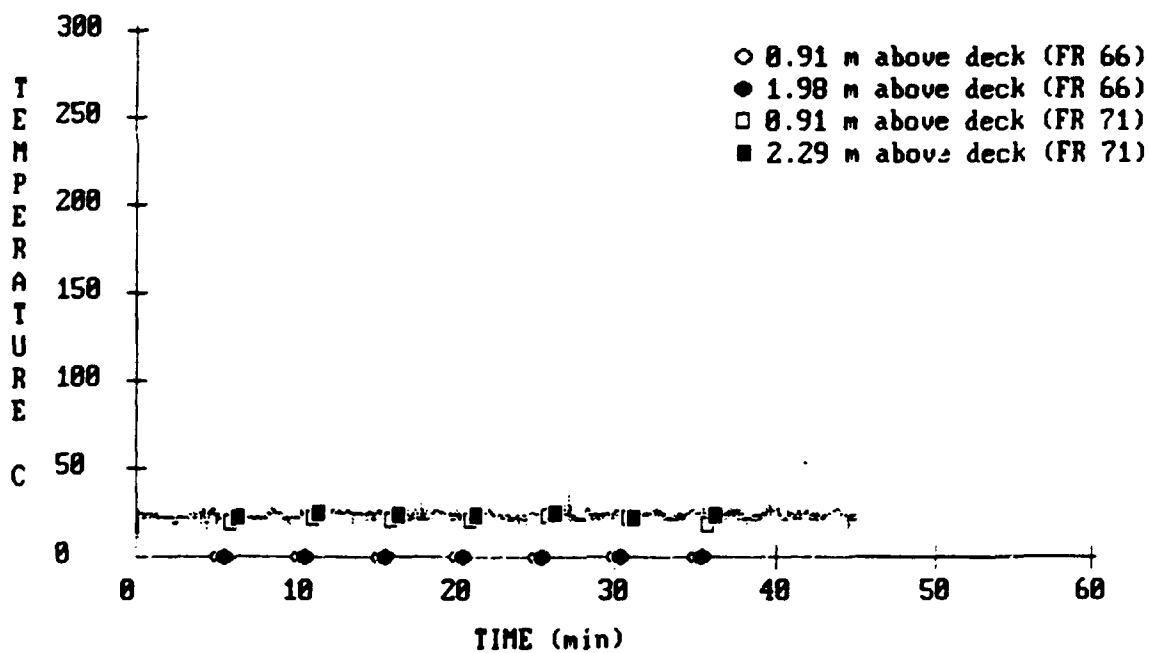


Fig. B-602- Temperature in the forward compartment during Test # 18

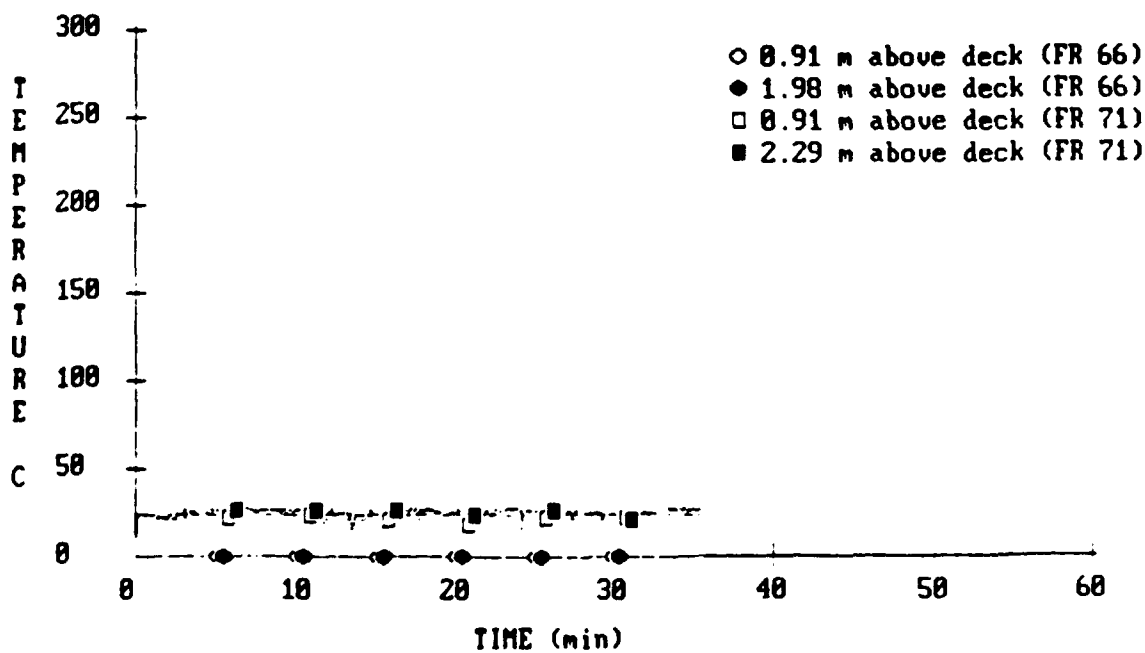


Fig. B-603- Temperature in the forward compartment during Test # 19

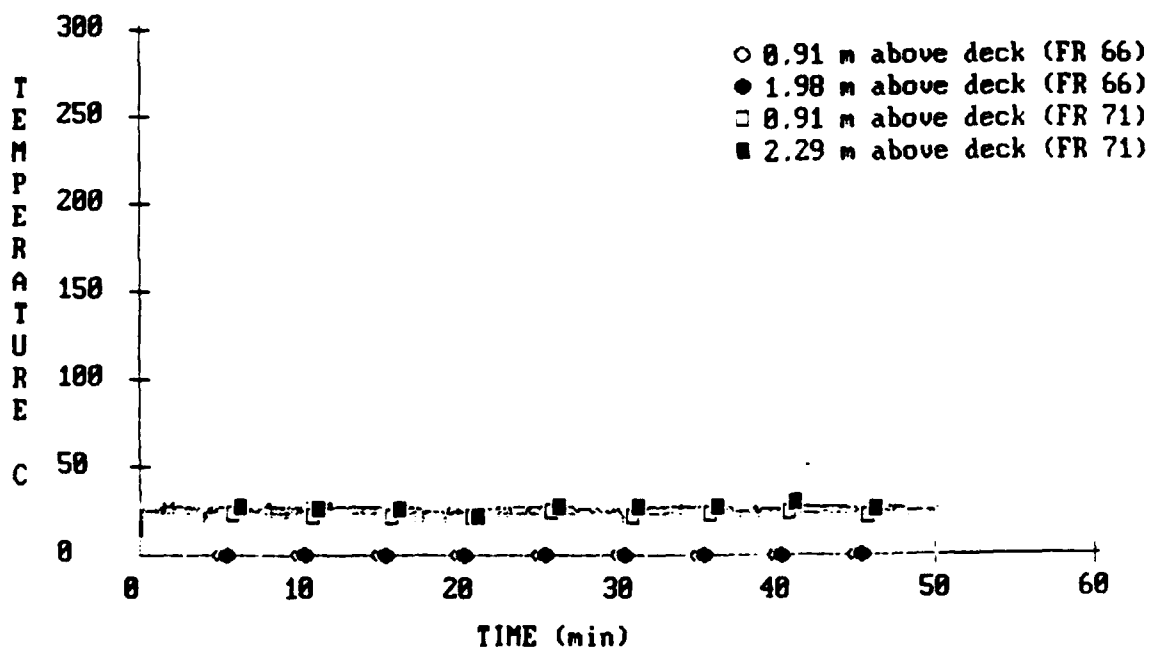


Fig. B-604- Temperature in the forward compartment during Test # 20

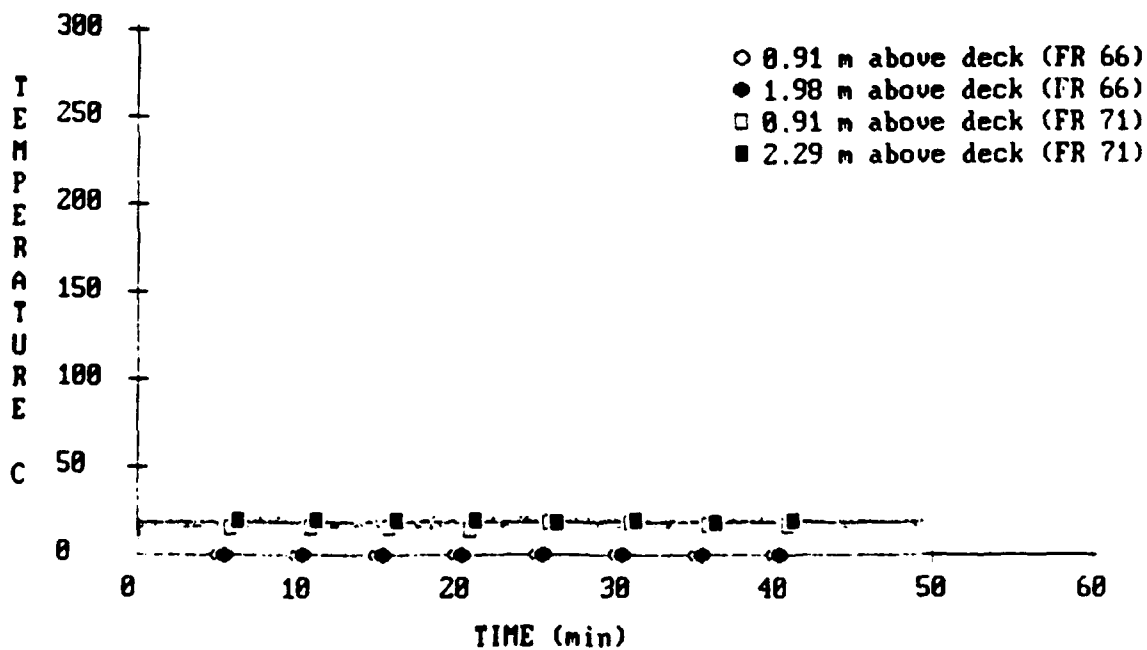


Fig. B-605- Temperature in the forward compartment during Test # 21

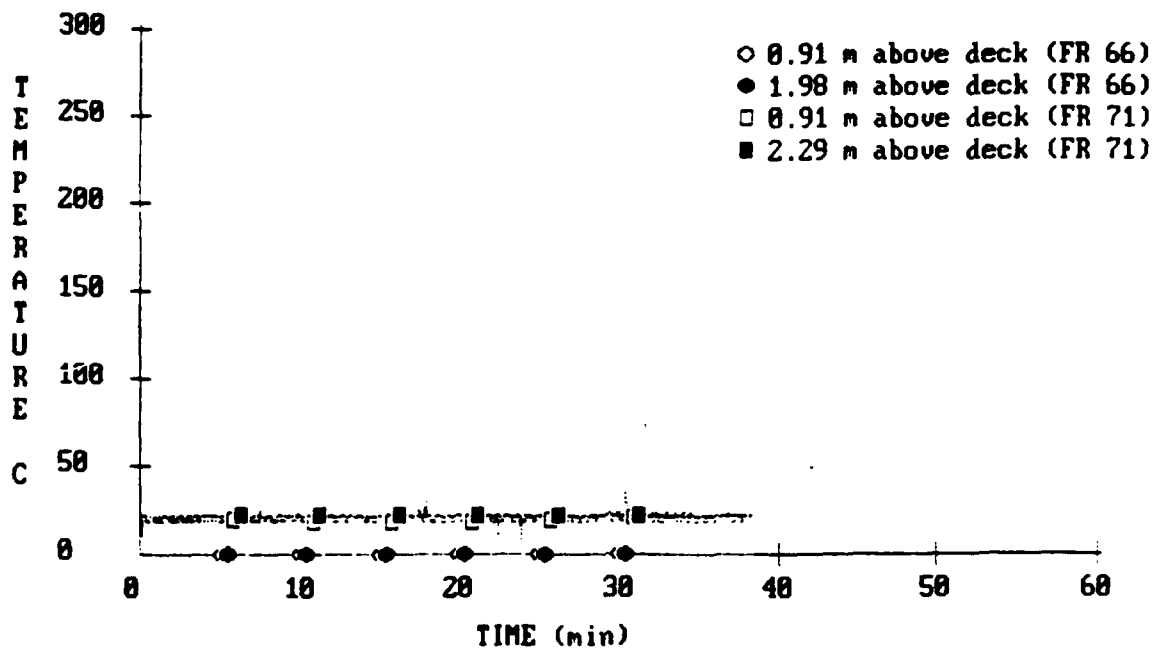


Fig. B-606- Temperature in the forward compartment during Test # 22

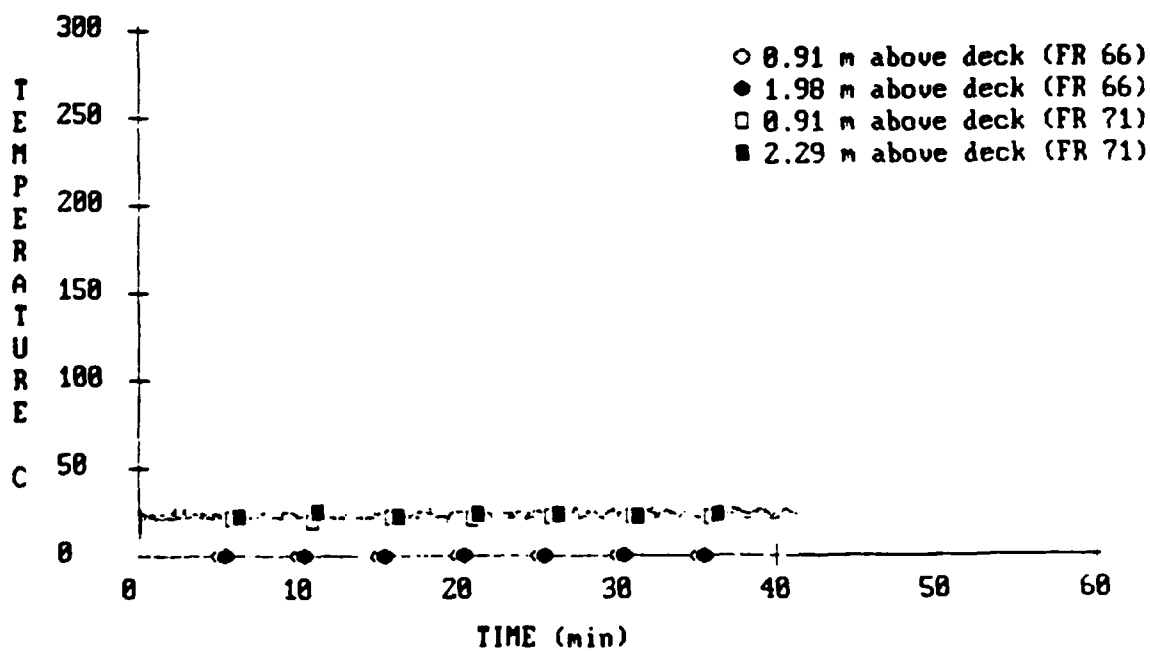


Fig. B-607- Temperature in the forward compartment during Test # 23

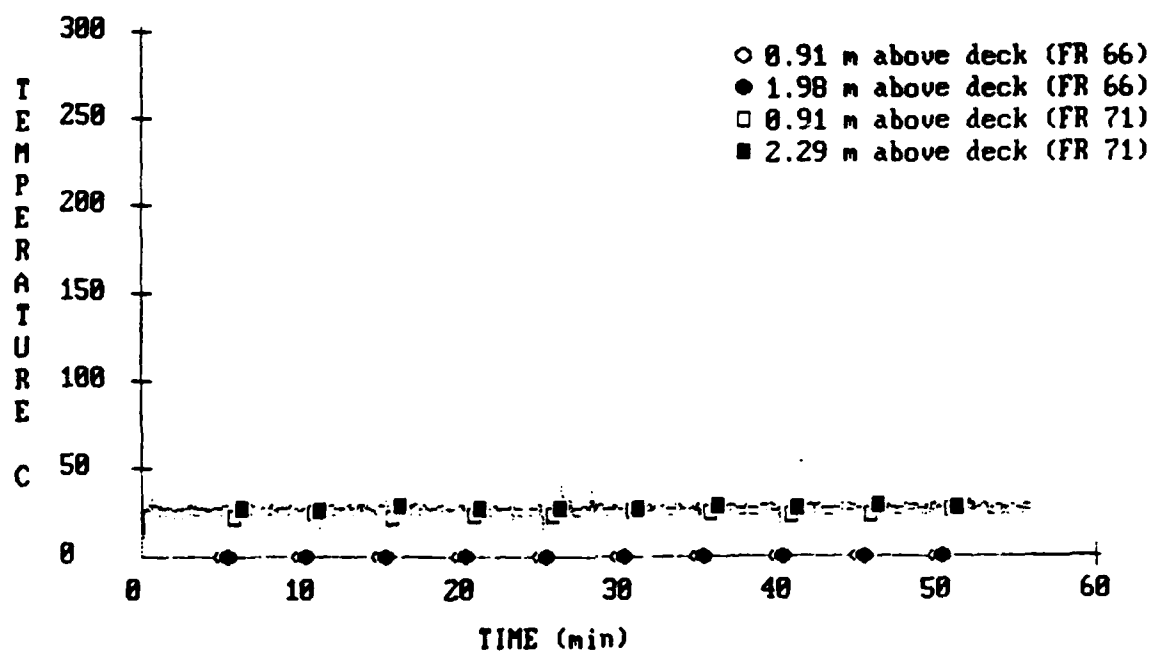


Fig. B-608- Temperature in the forward compartment during Test # 24

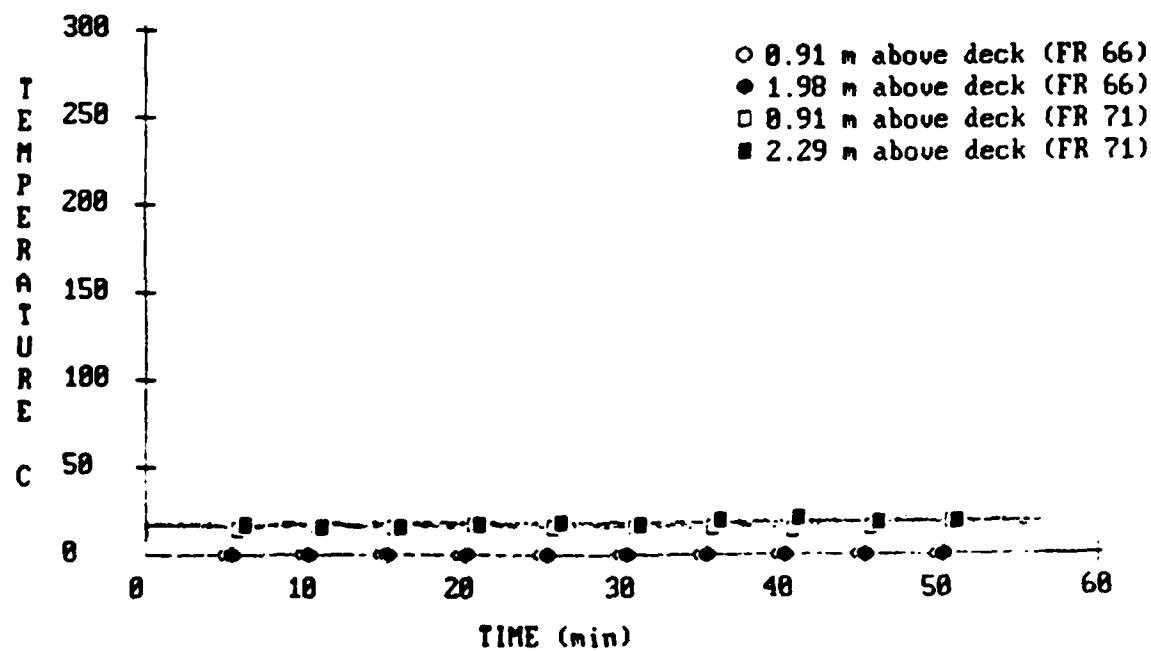


Fig. B-609- Temperature in the forward compartment during Test # 25

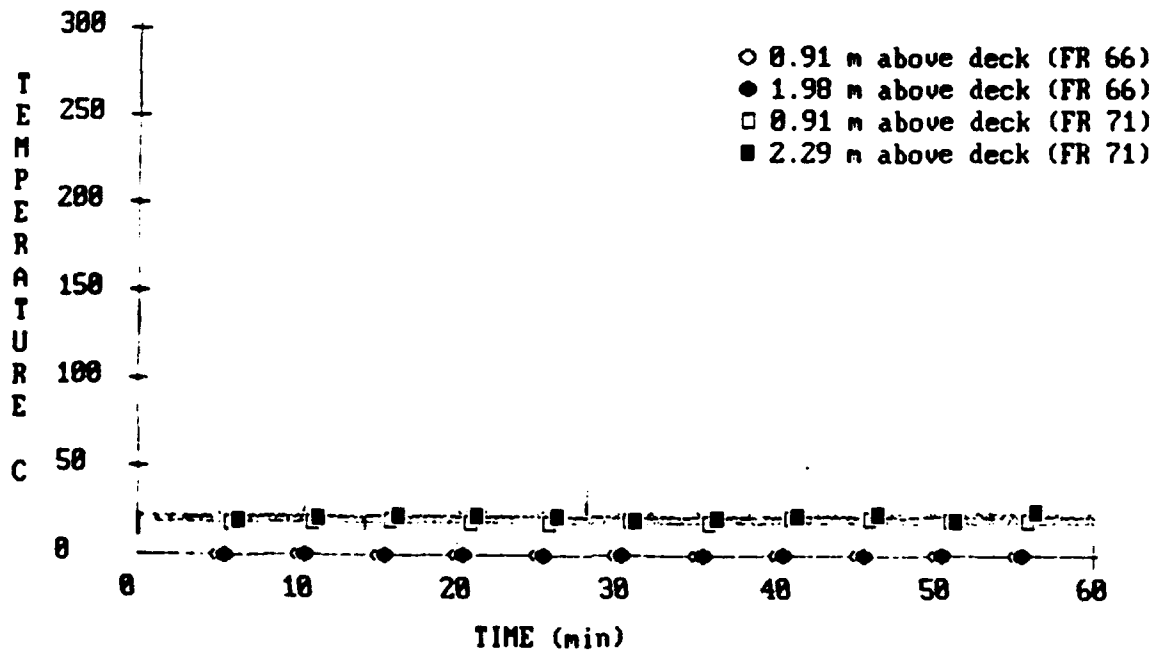


Fig. B-610- Temperature in the forward compartment during Test # 26

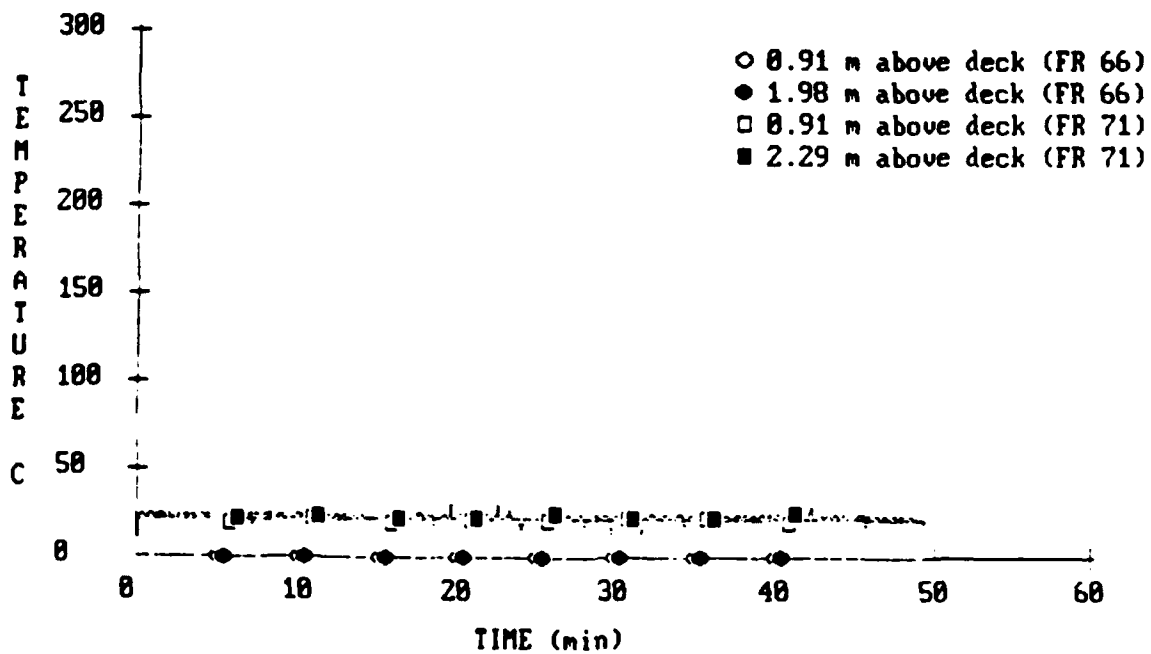


Fig. B-611- Temperature in the forward compartment during Test # 27

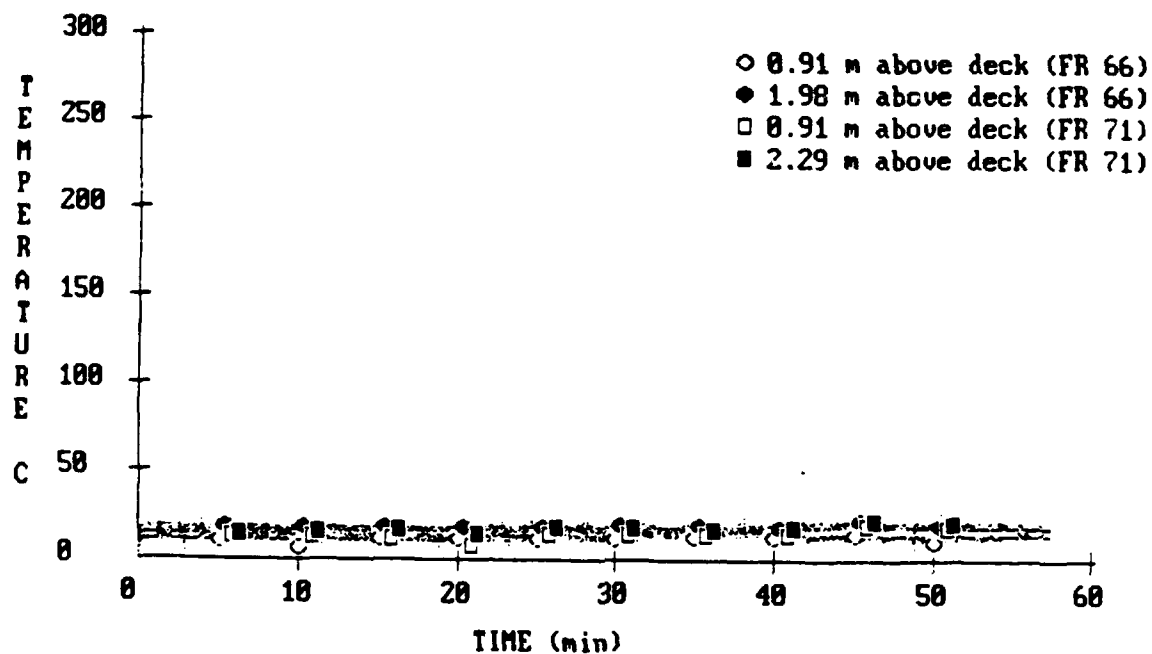


Fig. B-612- Temperature in the forward compartment during Test # 28

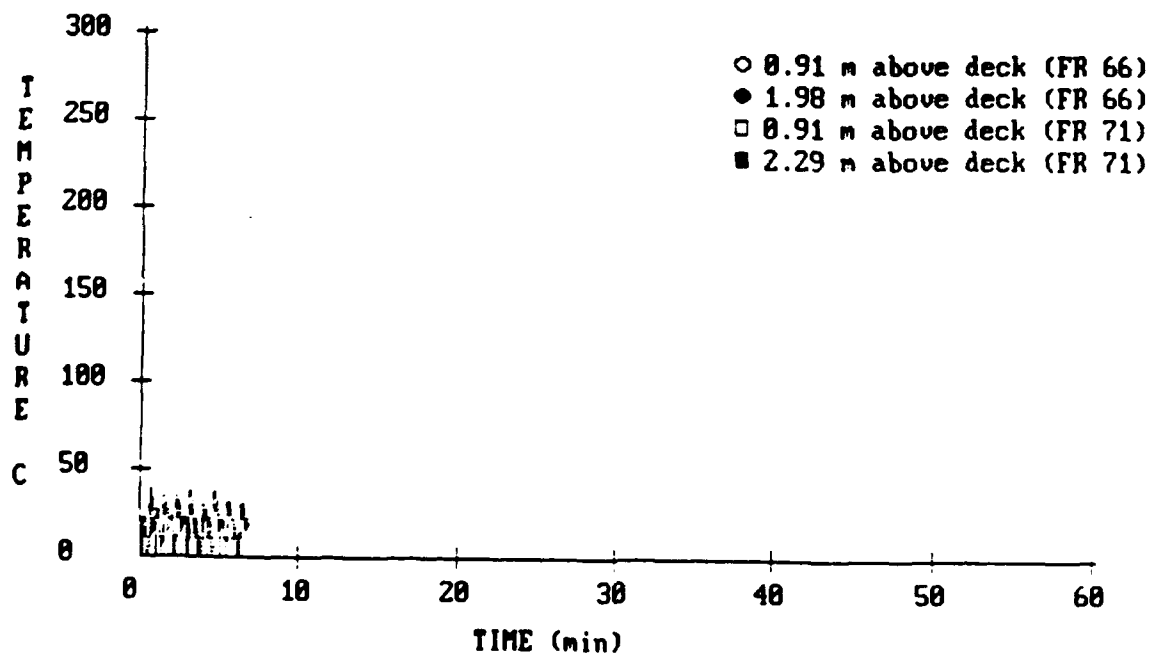


Fig. B-613- Temperature in the forward compartment during Test # 29



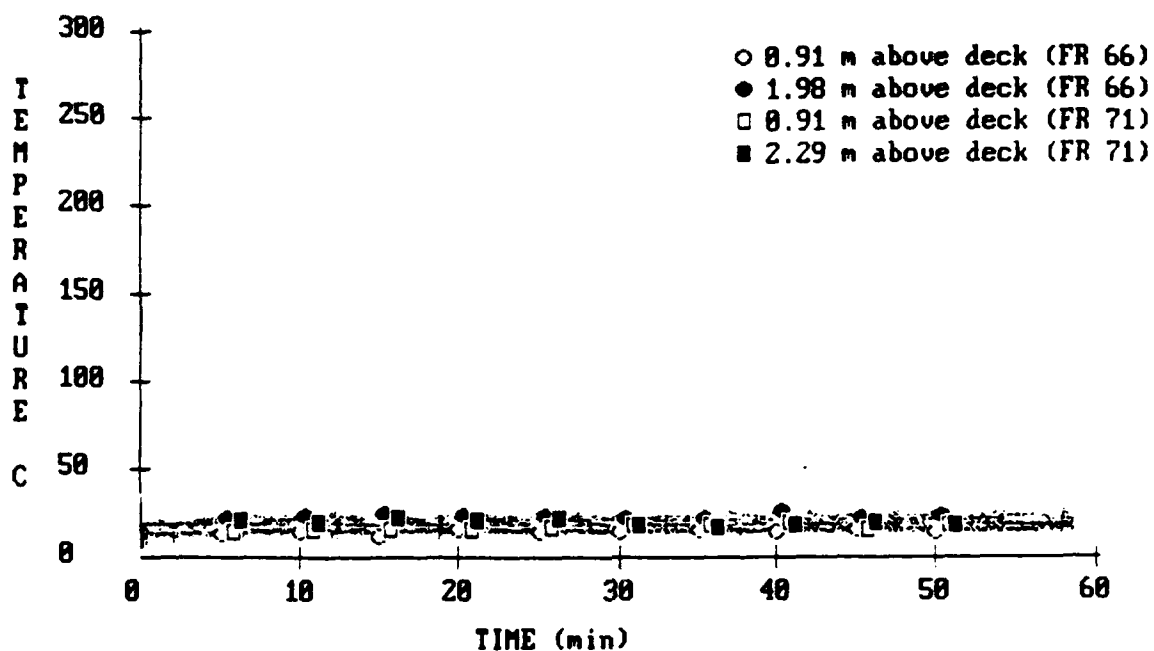


Fig. B-614- Temperature in the forward compartment during Test # 30

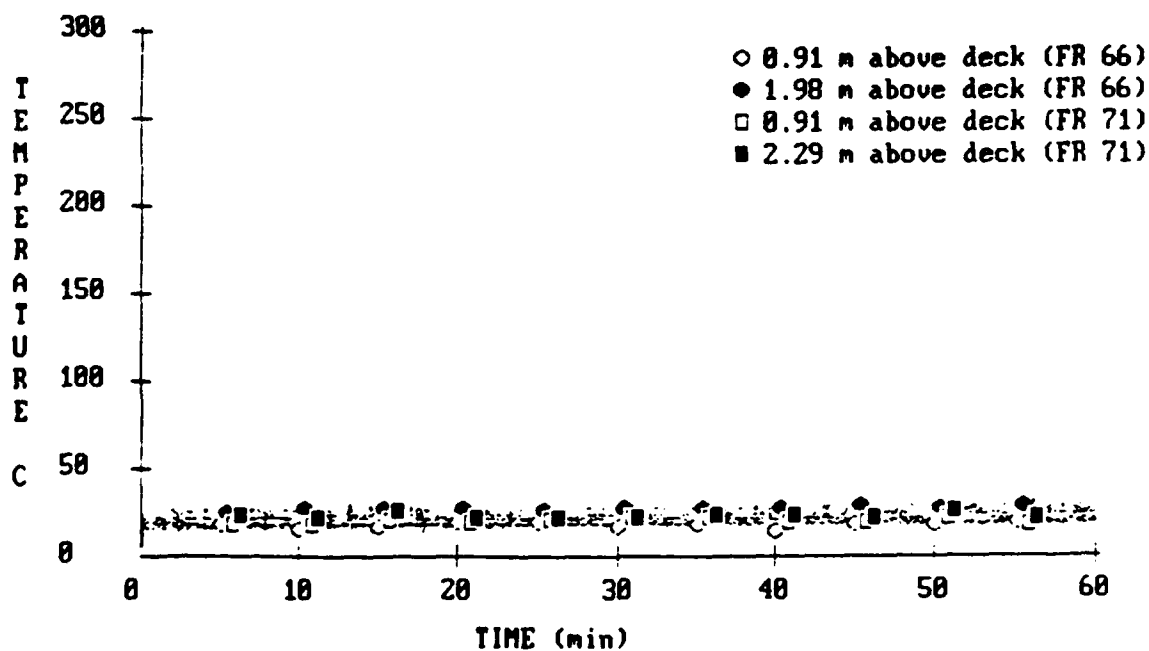


Fig. B-615- Temperature in the forward compartment during Test # 31

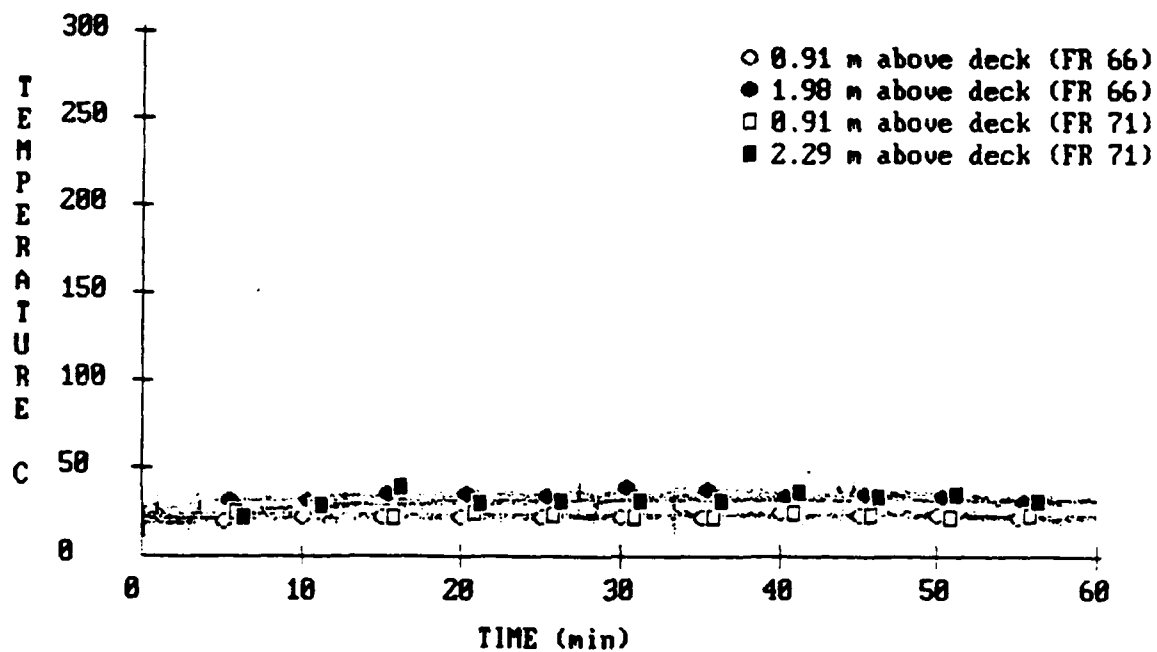


Fig. B-616- Temperature in the forward compartment during Test # 32

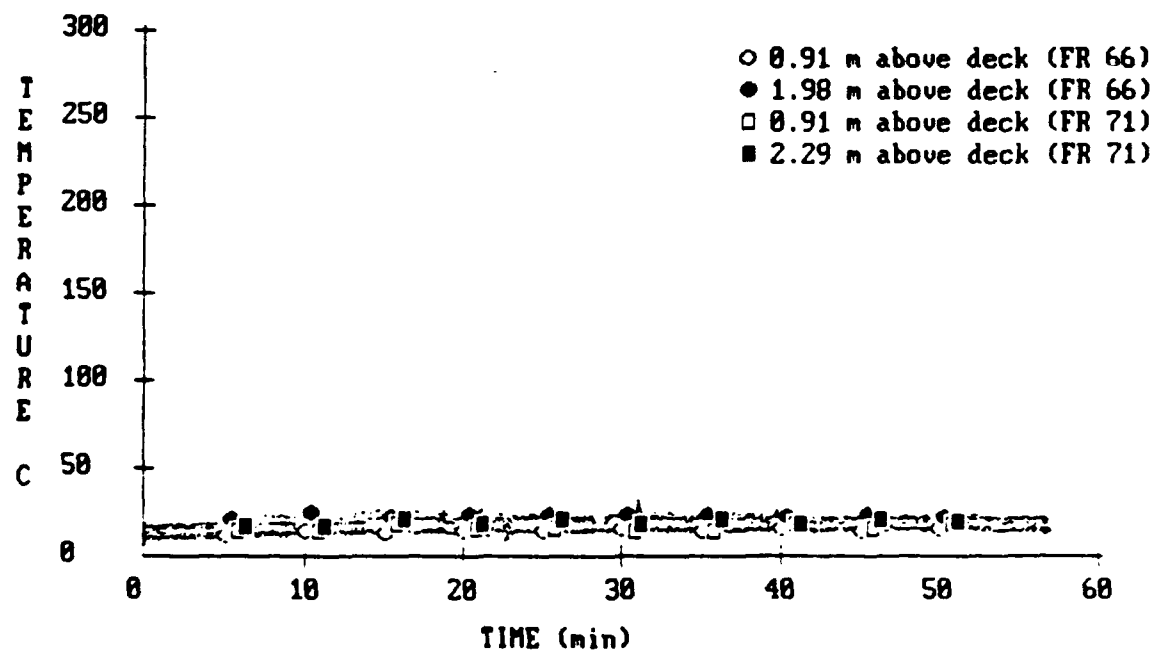


Fig. B-617- Temperature in the forward compartment during Test # 33

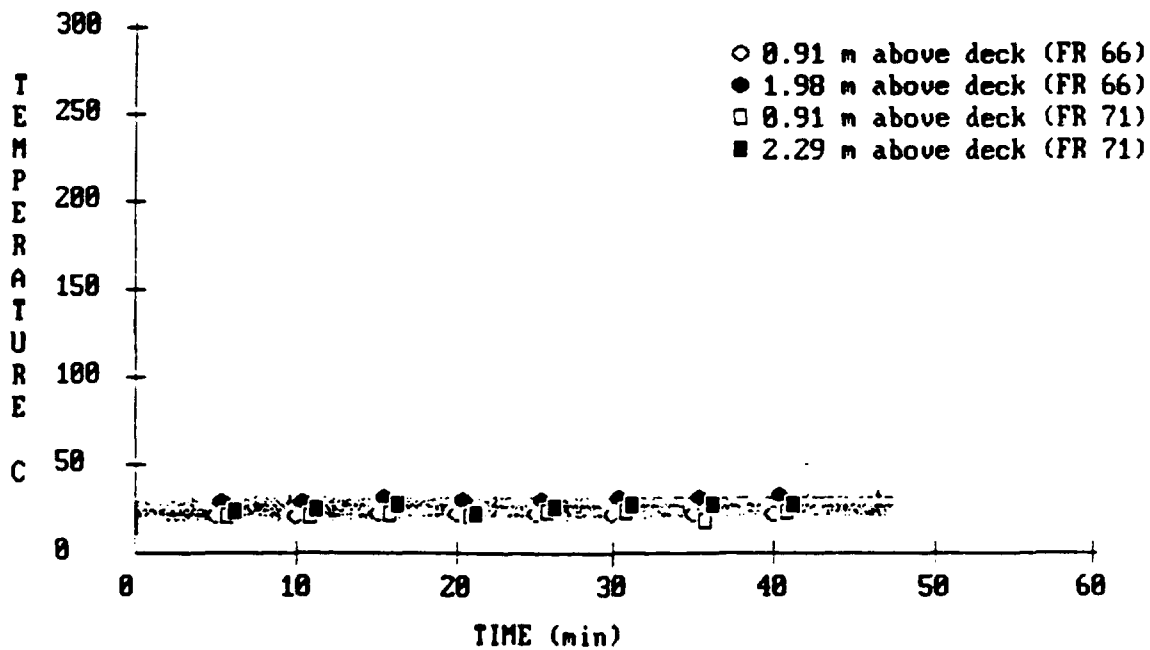


Fig. B-618- Temperature in the forward compartment during Test # 34

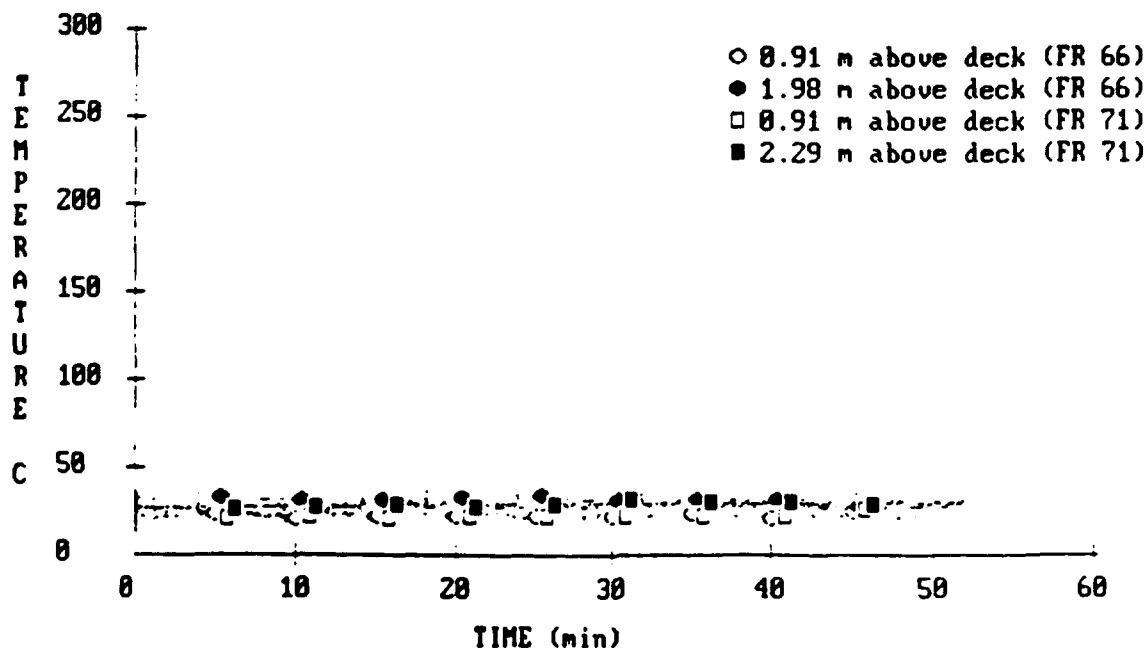


Fig. B-619- Temperature in the forward compartment during Test # 35

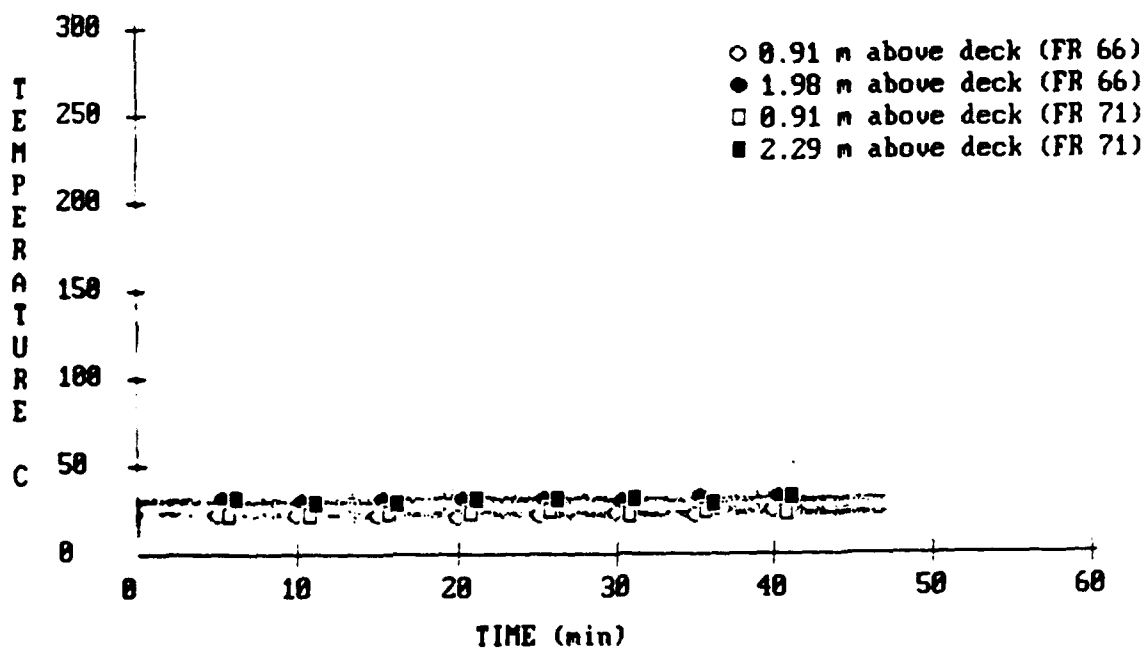


Fig. B-620- Temperature in the forward compartment during Test # 36

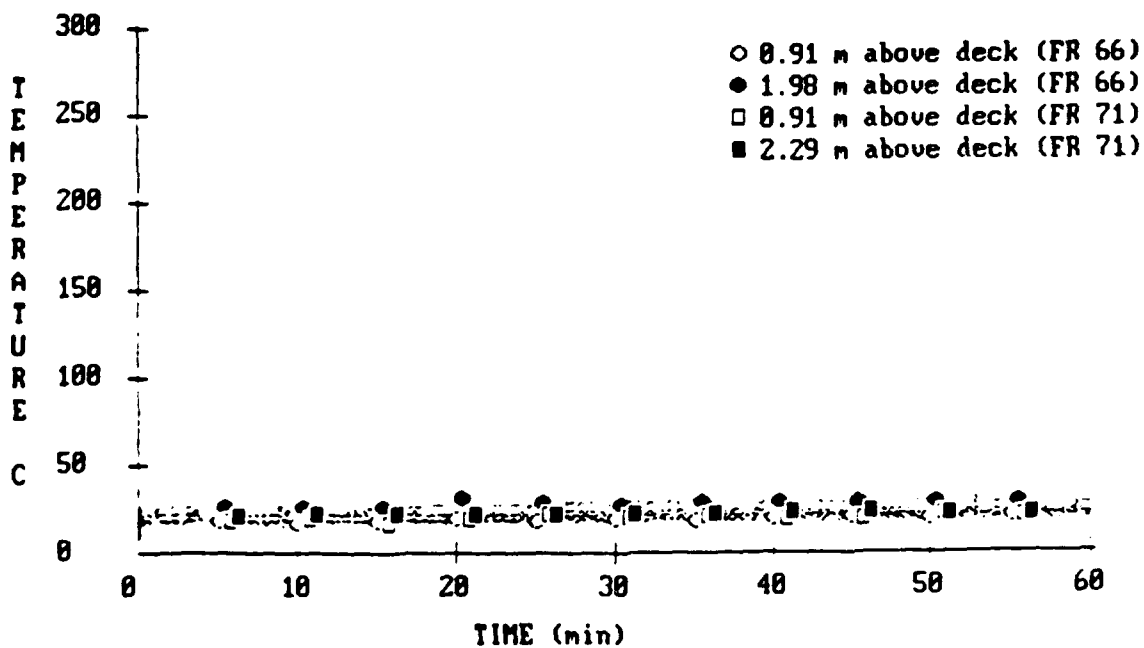


Fig. B-621- Temperature in the forward compartment during Test # 37

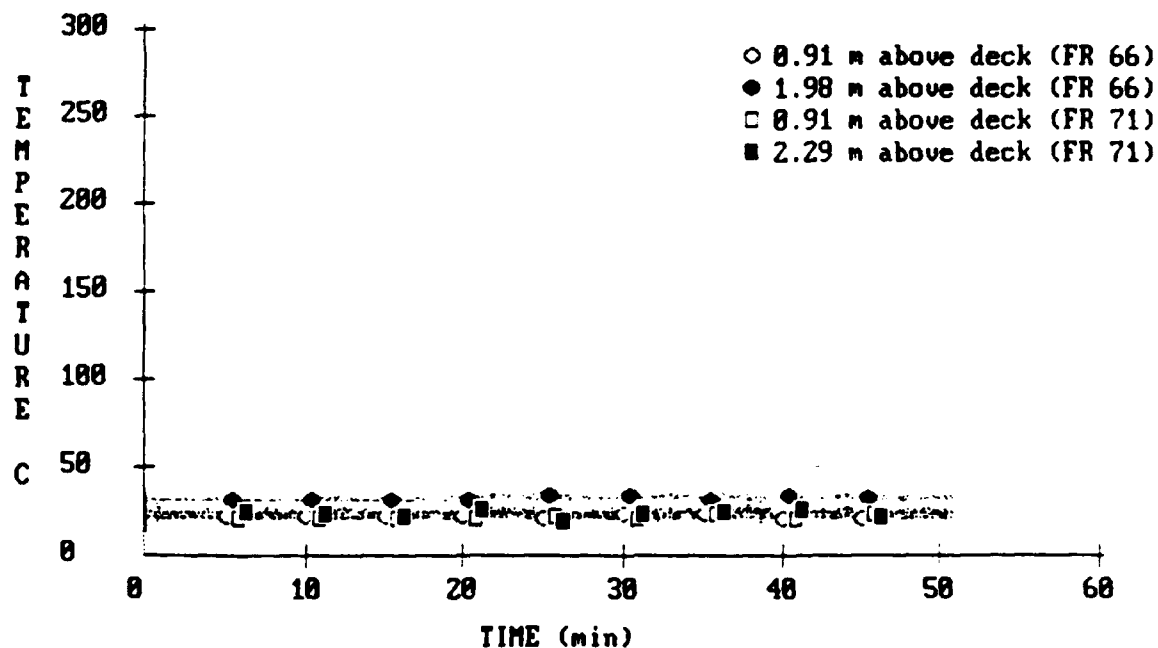


Fig. B-622- Temperature in the forward compartment during Test # 38

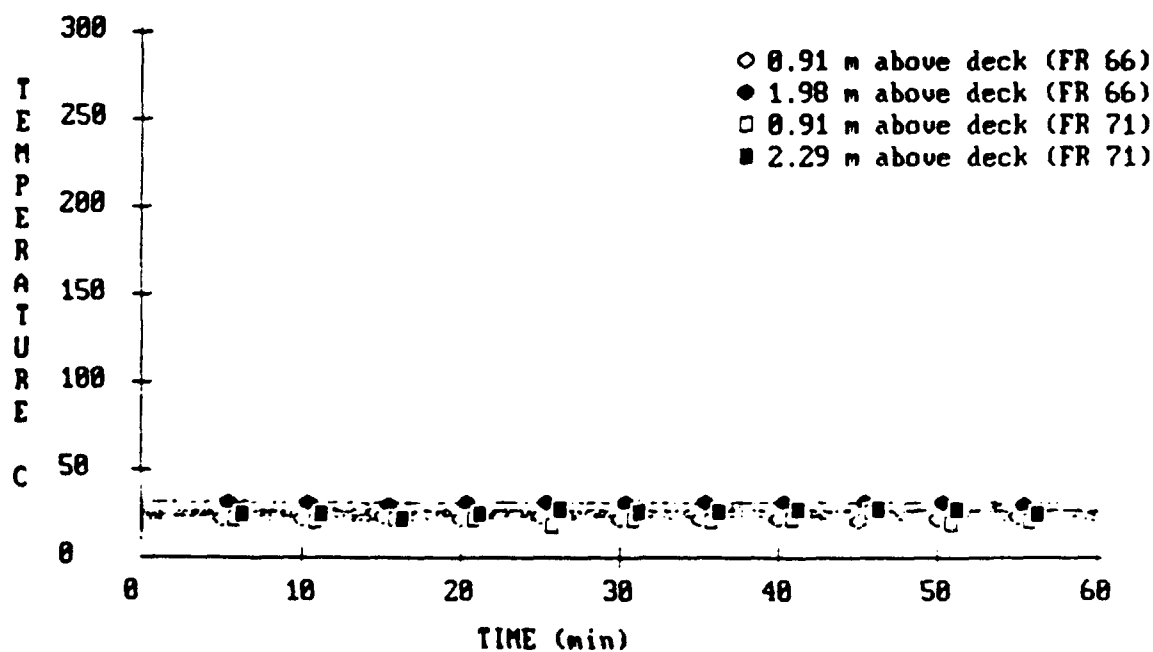


Fig. B-623- Temperature in the forward compartment during Test # 39

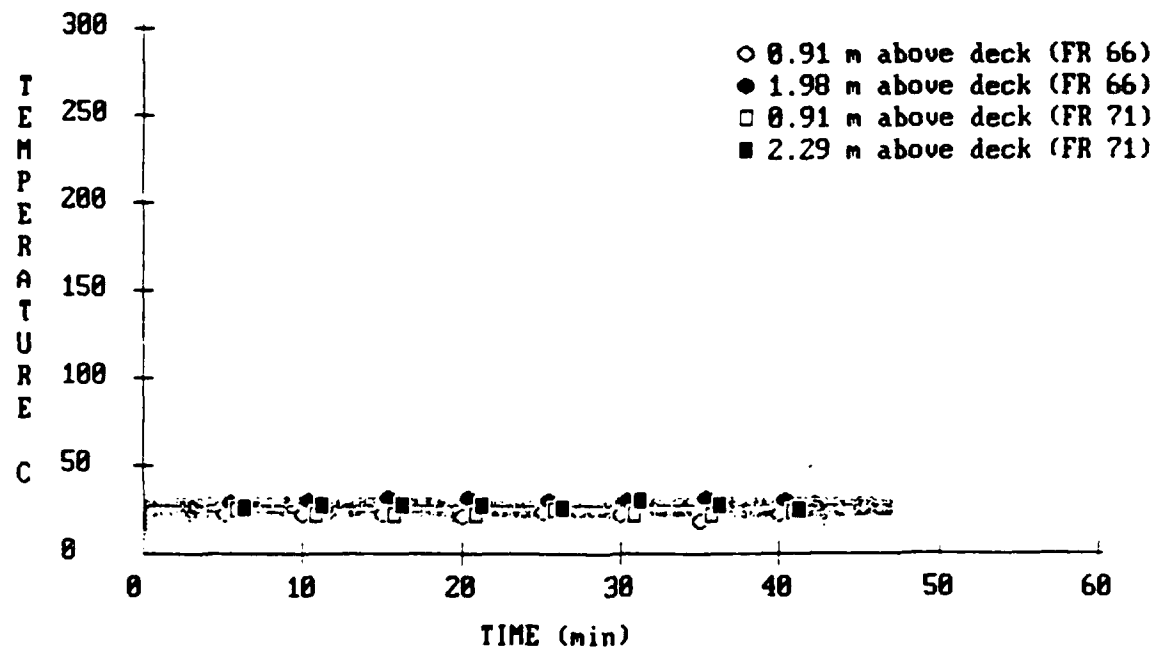


Fig. B-624- Temperature in the forward compartment during Test # 40

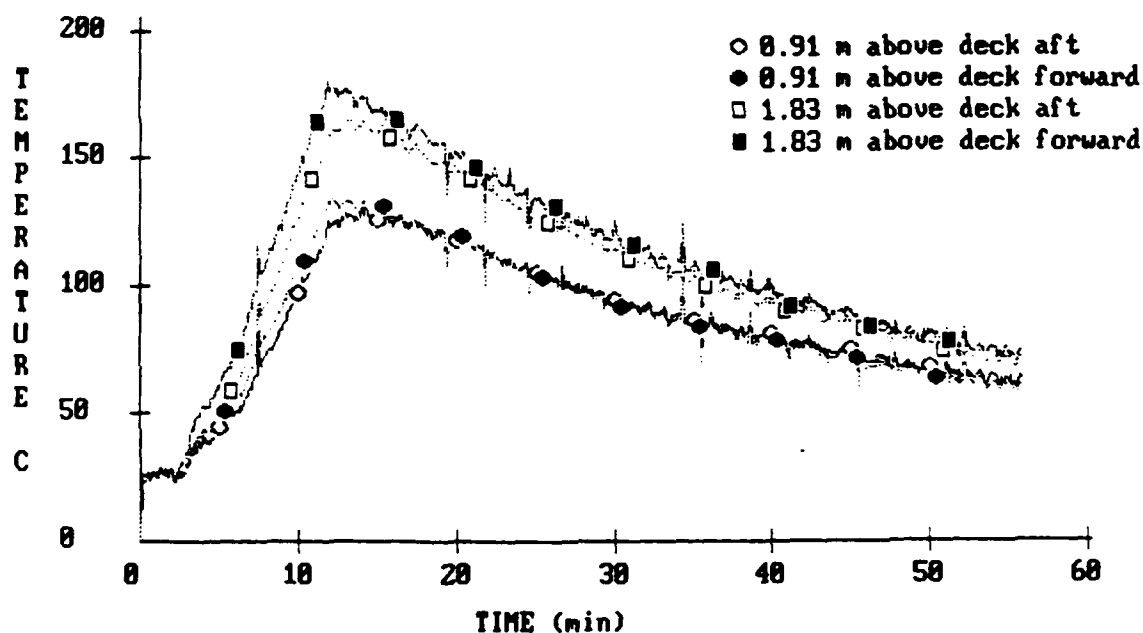


Fig. B-625- Bikh temperature in BERTHING 2 (3-88-2) during Test # 24

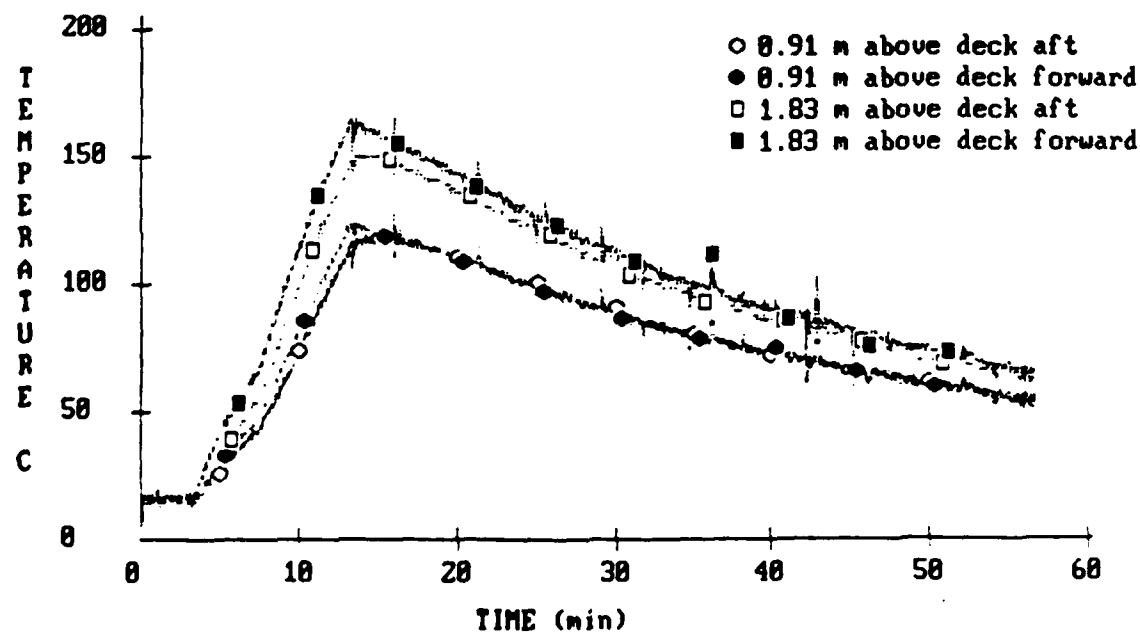


Fig. B-626- Bikh temperature in BERTHING 2 (3-88-2) during Test # 25

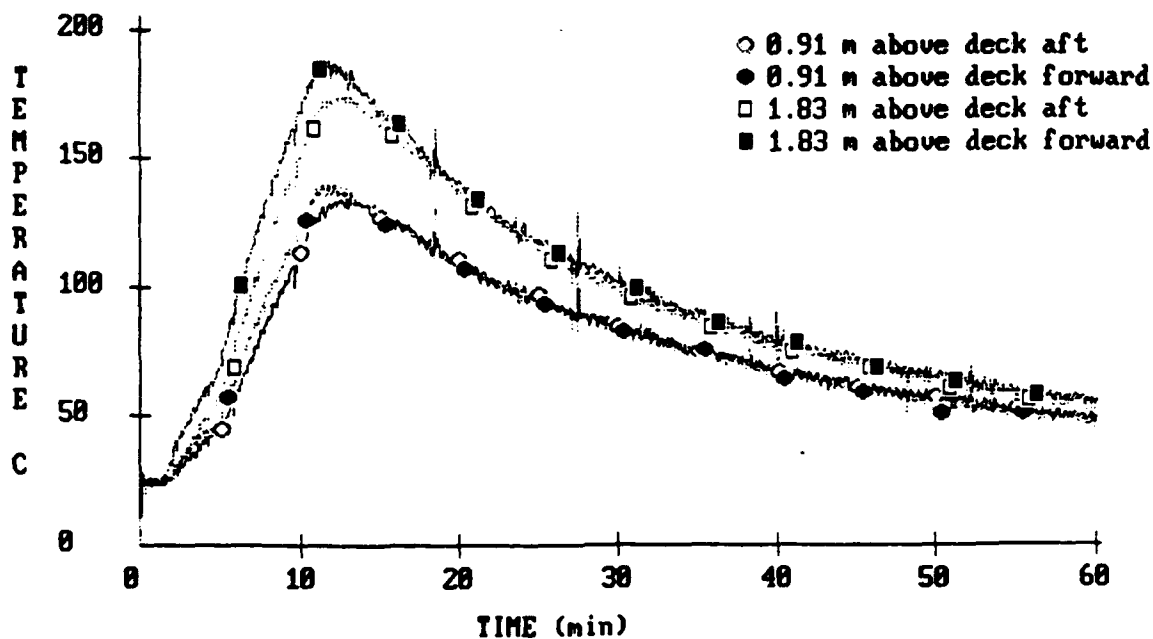


Fig. B-627- Blkhd temperature in BERTHING 2 (3-88-2) during Test # 26

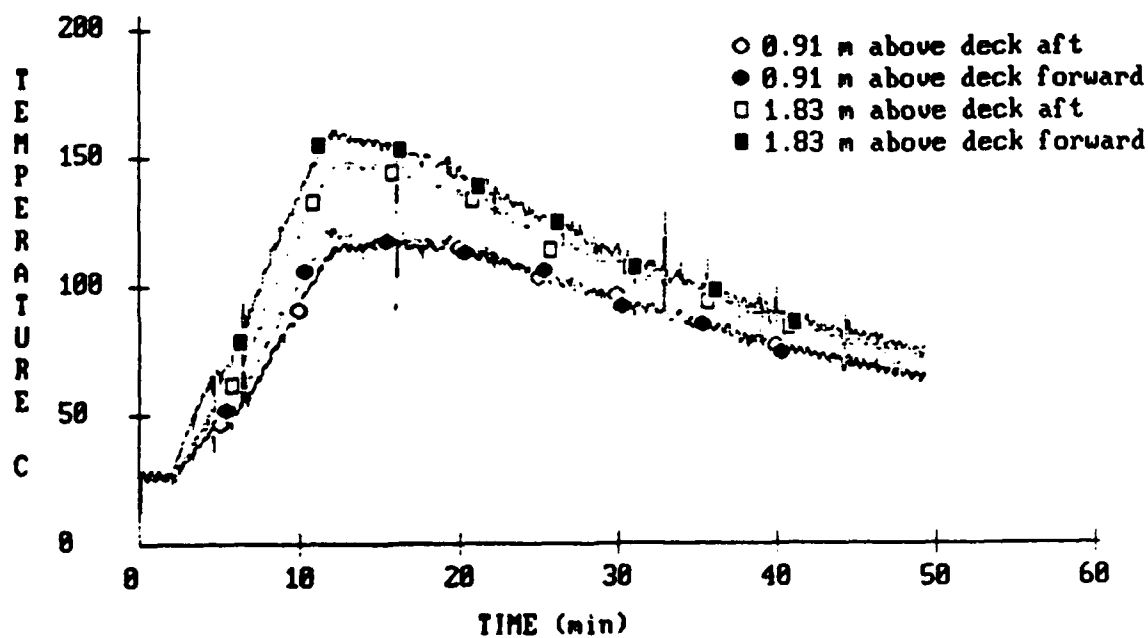


Fig. B-628- Blkhd temperature in BERTHING 2 (3-88-2) during Test # 27



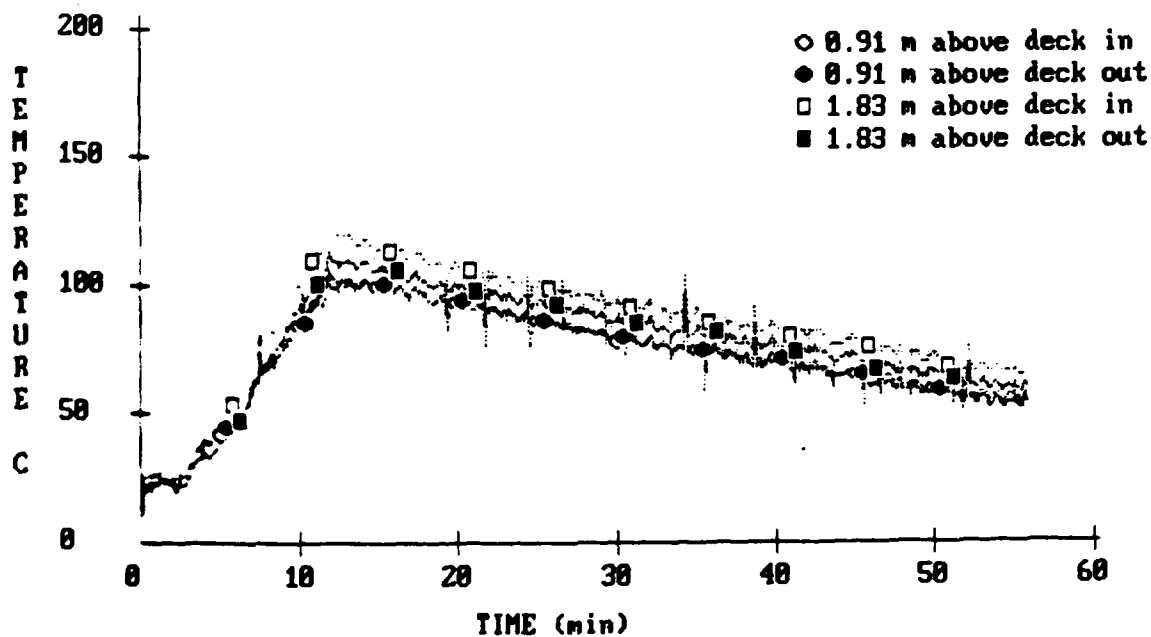


Fig. B-629- Bulkhead temperature in BERTHING 2 (3-88-2) during Test # 24

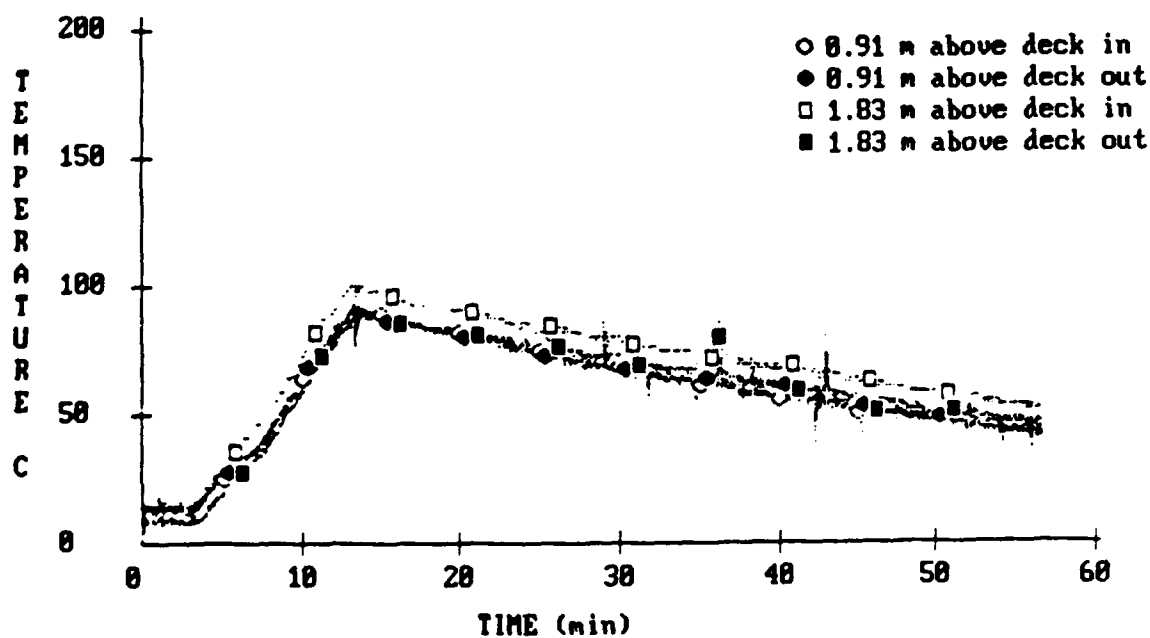


Fig. B-630- Bulkhead temperature in BERTHING 2 (3-88-2) during Test # 25

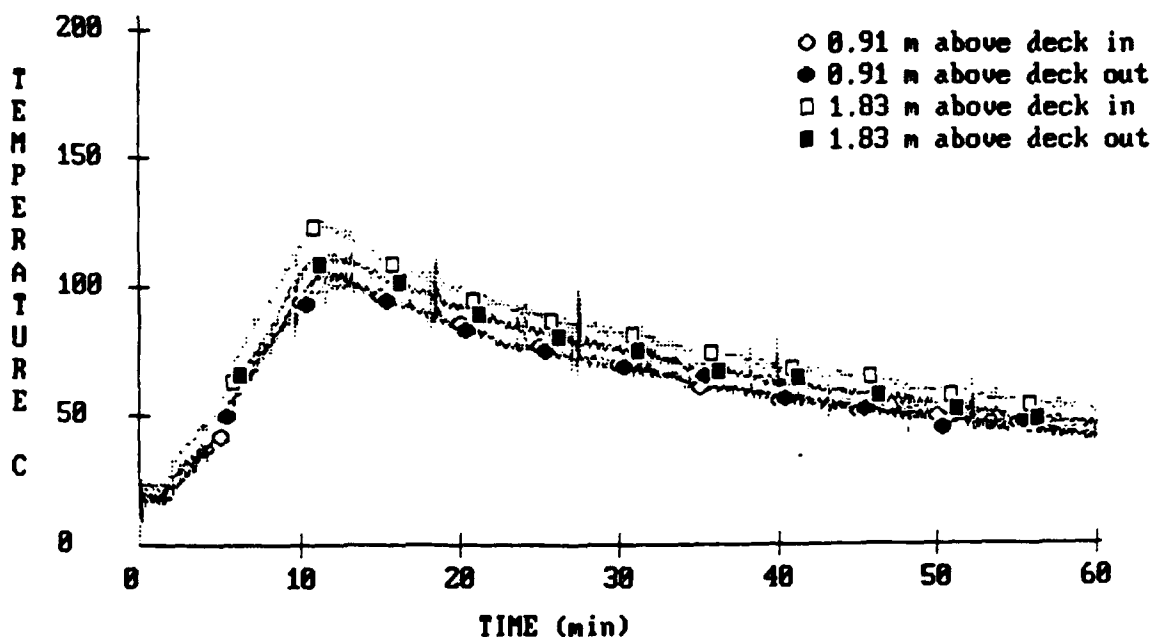


Fig. B-631- Bulkhead temperature in BERTHING 2 (3-88-2) during Test # 26

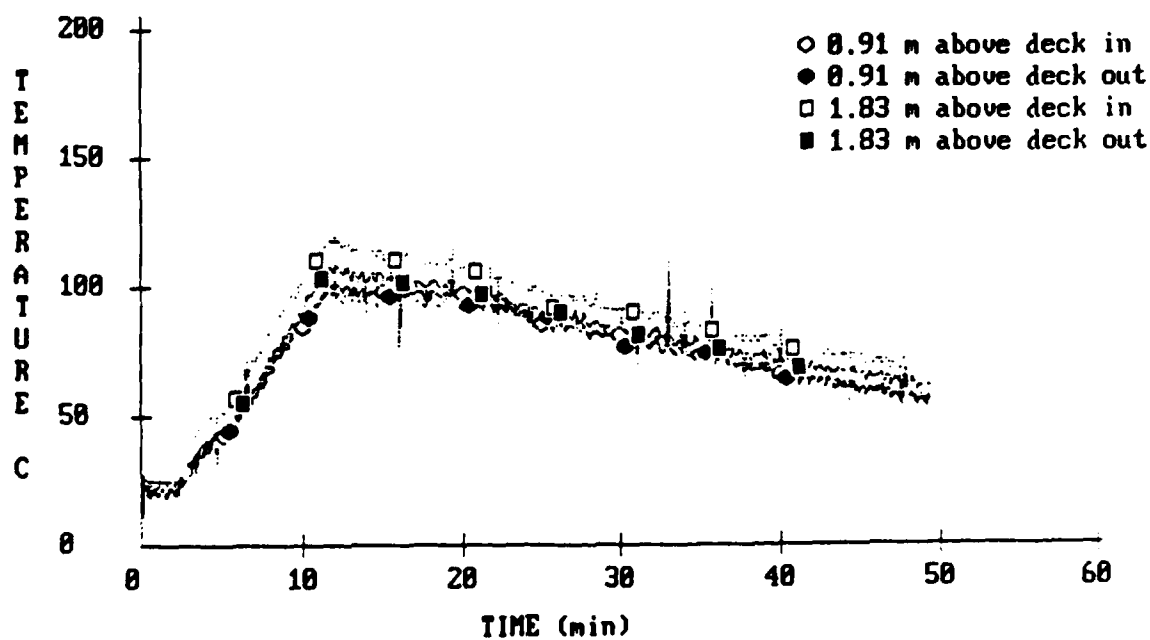


Fig. B-632- Bulkhead temperature in BERTHING 2 (3-88-2) during Test # 27

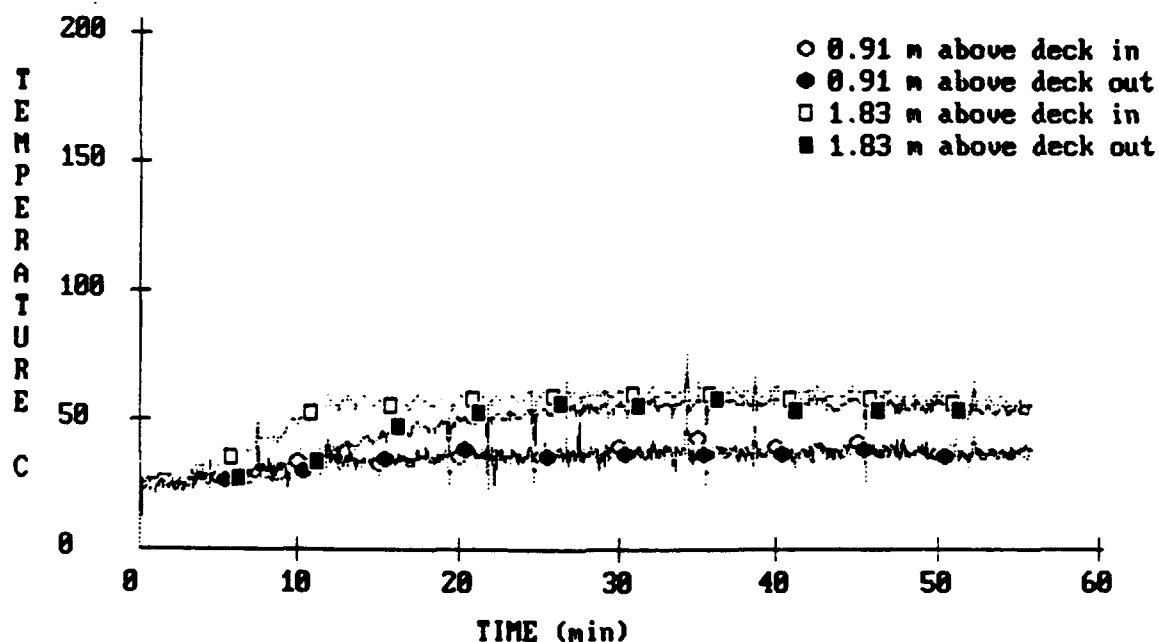


Fig. B-633. Bulkhead temperature in BERTHING 2 (3-86-2) during Test # 24

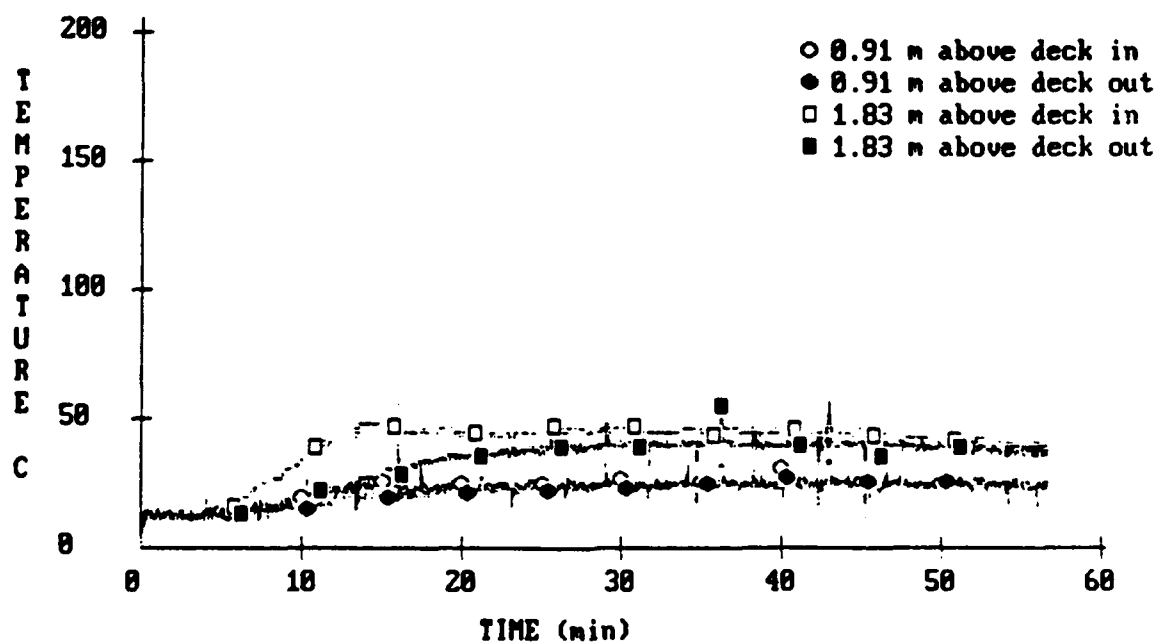


Fig. B-634. Bulkhead temperature in BERTHING 2 (3-86-2) during Test # 25

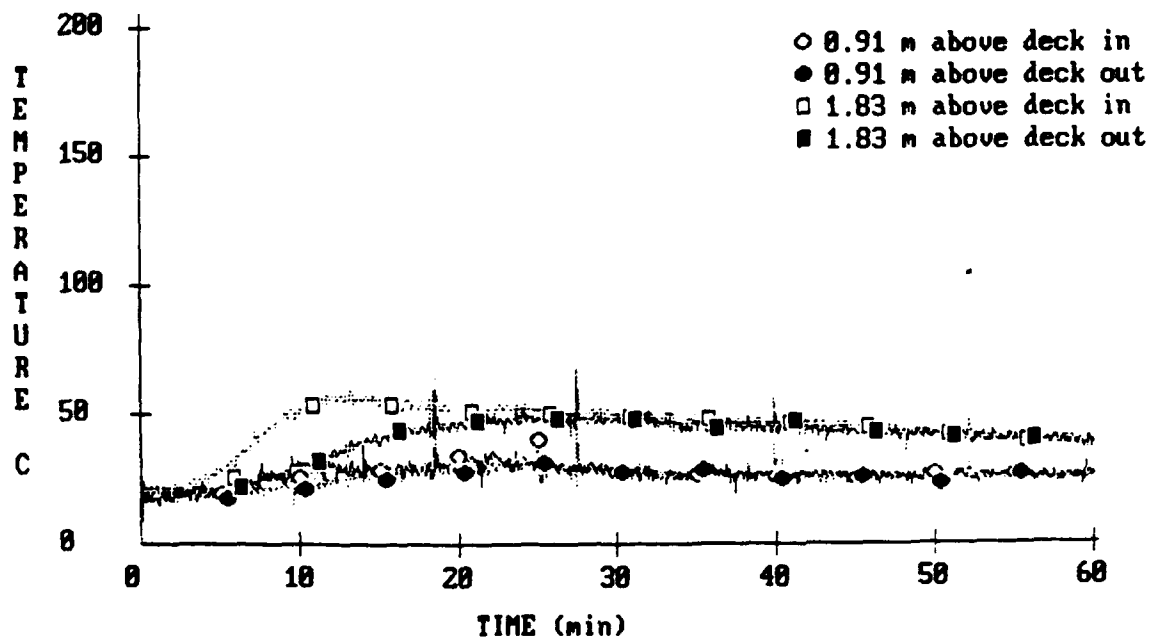


Fig. B-635- Bulkhead temperature in BERTHING 2 (3-86-2) during Test # 26

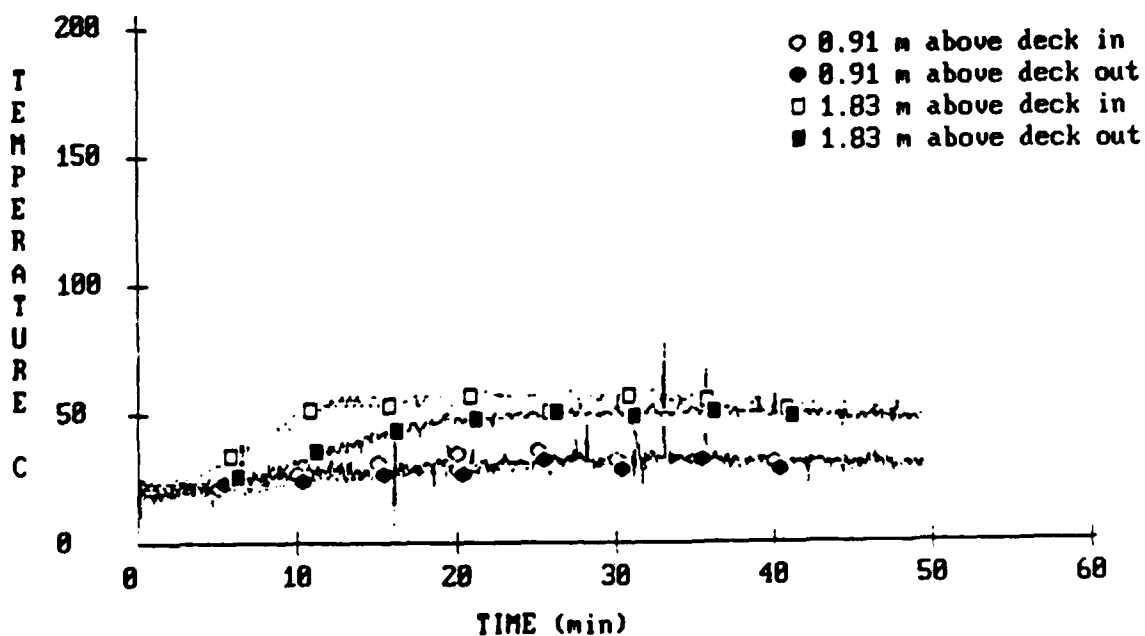


Fig. B-636- Bulkhead temperature in BERTHING 2 (3-86-2) during Test # 27

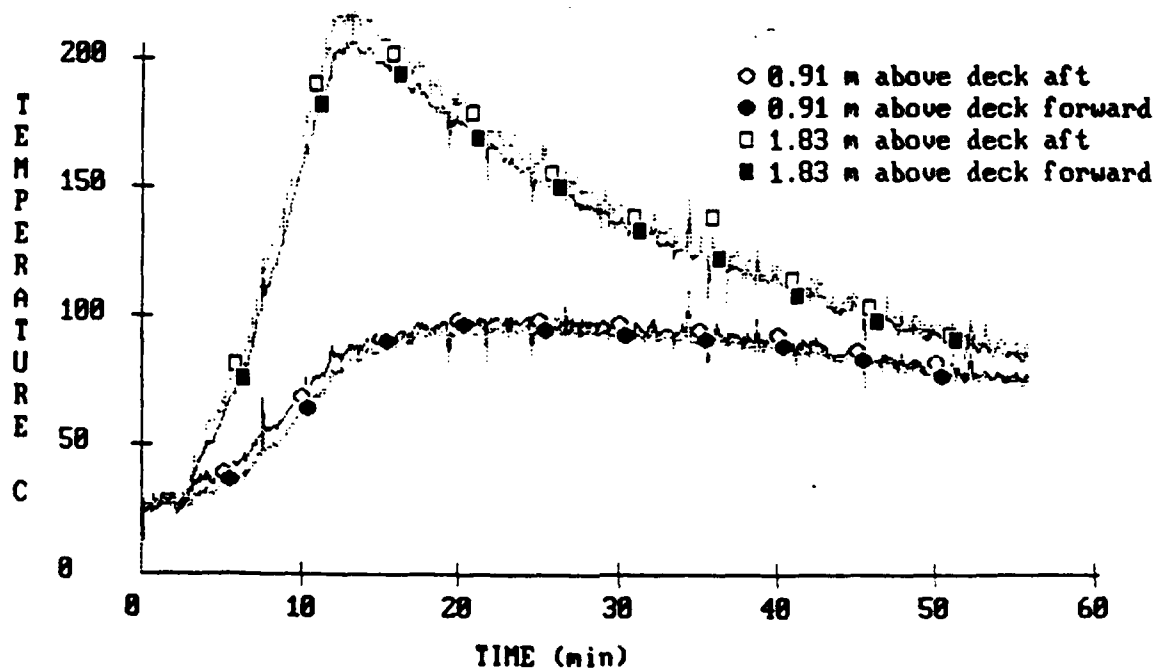


Fig. B-637- Blkhd temperature in BERTHING 2 (3-81-2) during Test # 24

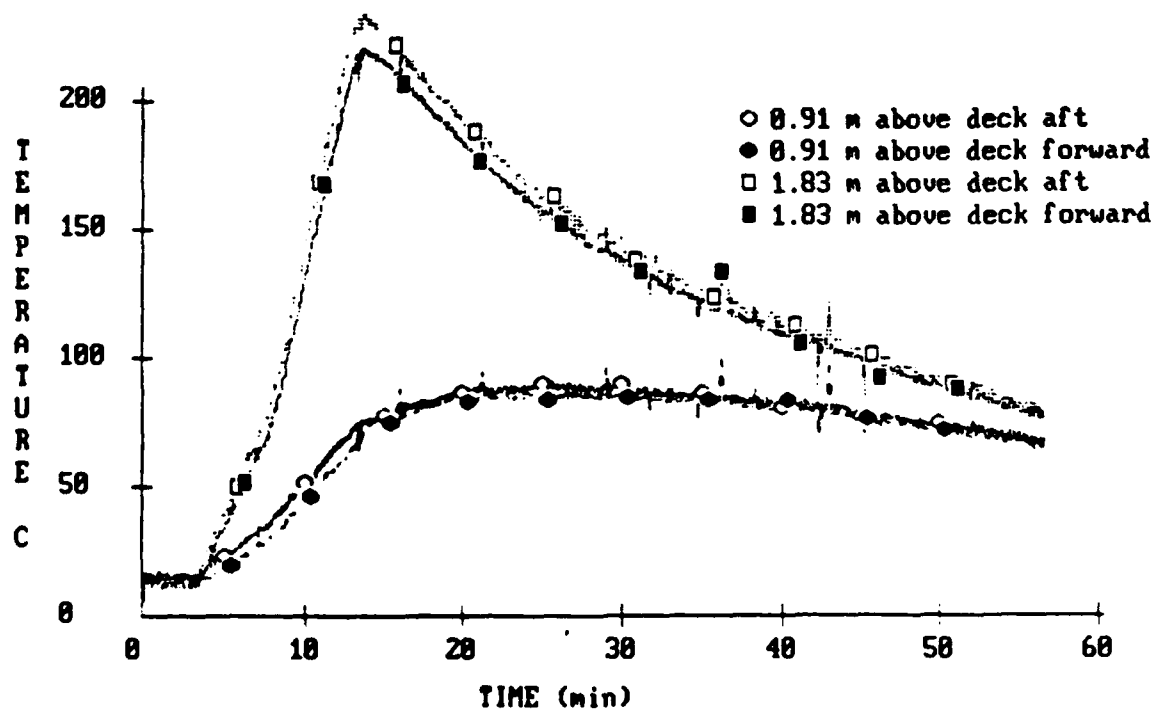


Fig. B-638- Blkhd temperature in BERTHING 2 (3-81-2) during Test # 25

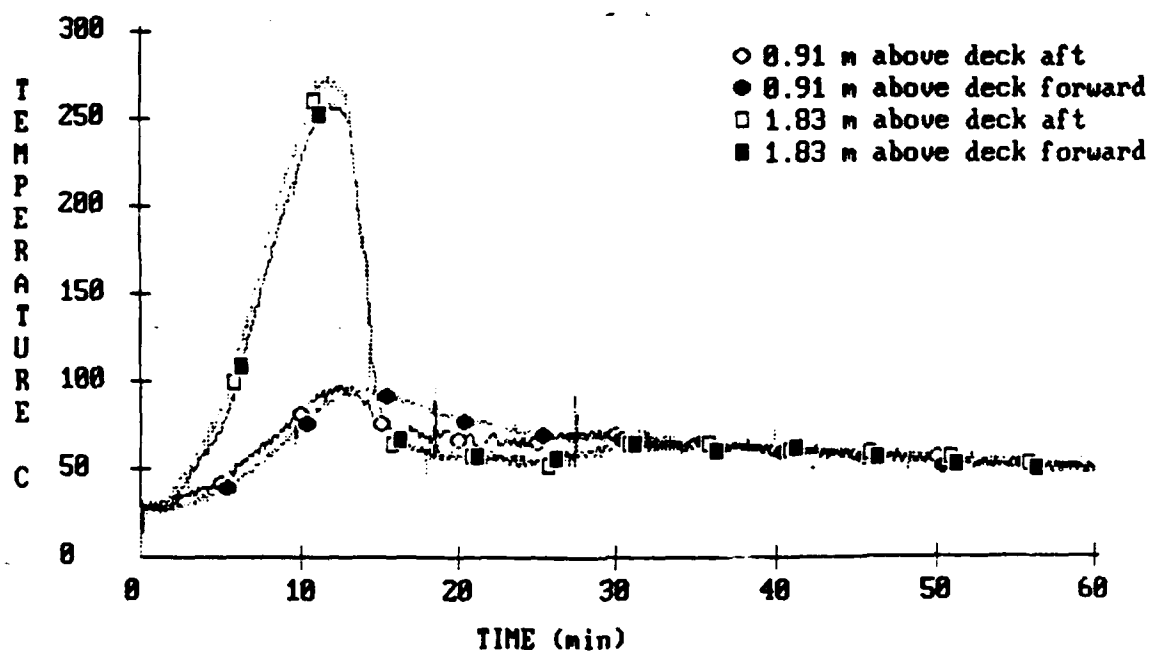


Fig. B-639- Blkhd temperature in BERTHING 2 (3-81-2) during Test # 26

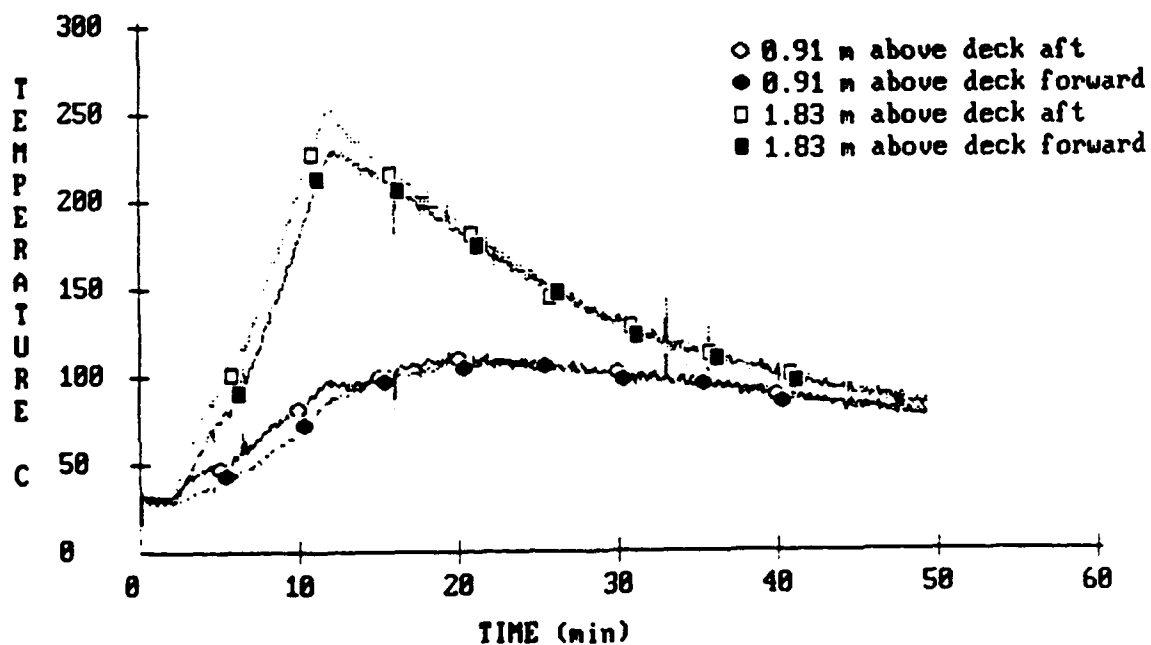


Fig. B-640- Blkhd temperature in BERTHING 2 (3-81-2) during Test # 27

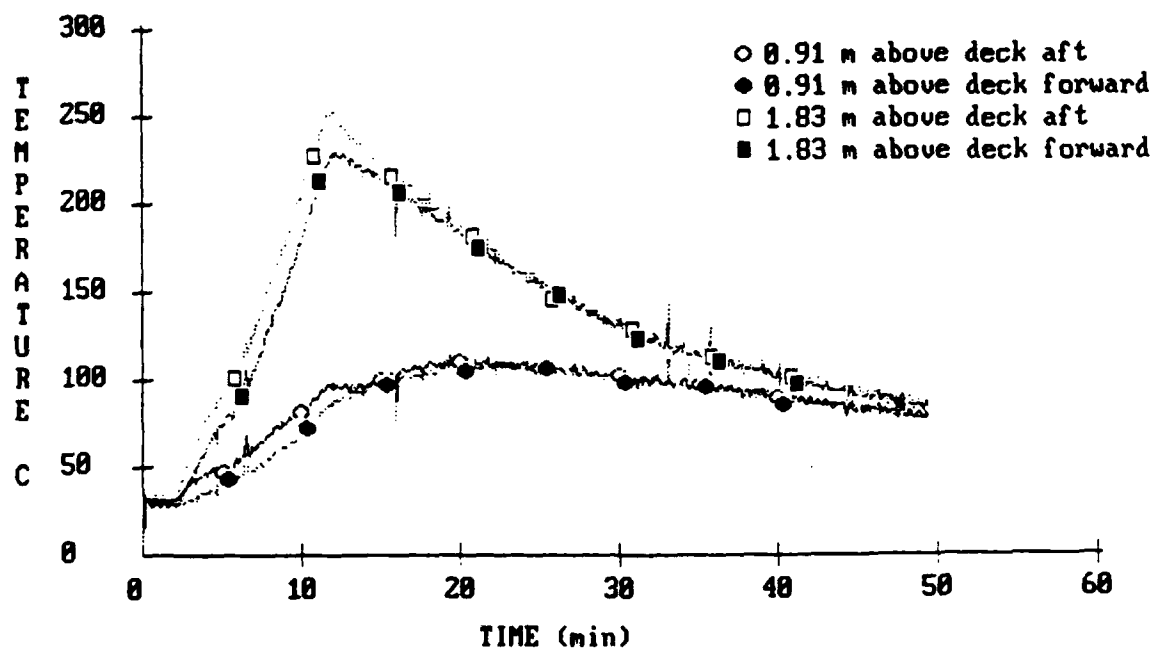


Fig. B-641- Blkhd temperature in BERTHING 2 (3-81-2) during Test # 27

## **APPENDIX C**

### **Guidance for the Development of Doctrine Tactics and Procedures for the Water Motor Fan**



## **Appendix C**

### **Guidance for the Development of Doctrine, Tactics and Procedures for the Water Motor Fan**

#### **BACKGROUND**

The data from the test series described in this report provides the basis for procedures to use the water motor fan in damage control scenarios, specifically fires. This information must be integrated into ships' technical manuals and training curricula/guides. The intent of this appendix is to provide a strawman outline for the development of the procedural documentation. The basis of this strawman outline is the results from these tests, experience from previous NRL doctrine and tactics tests (Refs. C1 - C8), and currently available ventilation/smoke control doctrine (Refs. C9 - C12).

#### **IMPLEMENTATION**

The development of this strawman assumes that the WMF units and ducts will be allocated on the same basis as current Red Devil Blowers. This will assure availability during emergencies. At a minimum, one unit per Repair Party should be provided. Training on WMF operations should be conducted at FTC's and FTG's and during each ship's routine exercises. This should be reflected in FXP-3 "Fleet Exercise Manual" requirements. It should also be reflected in Personnel Qualification Standards for Damage Control Emergency Parties.

It is anticipated that setup and operation of the WMF would normally be assigned to the ship's Desmoking Team. Activating it should not require any special authorization or skill as with the Red Devil Blower.

#### **TACTICAL CONSIDERATIONS FOR VENTING**

##### **General Considerations**

All ships are faced with ventilation challenges from time to time. There may be failure of the installed ventilation systems or administrative requirements for "Gas Freeing" compartments for work. There is always the potential for unpredictable events surrounding accidents or combat induced casualties.

Dealing with ventilation failures and restoring ventilation are challenges which Navy ships are generally well prepared to meet. There exists a variety of response options. These reflect consideration for the factors influencing the decisions necessary to establish

the most appropriate ventilation. Factors to consider in deciding how to respond to ventilation needs and how to prioritize the response include

- cause of lost ventilation;
- result of loss or lack of ventilation;
- external threat (environment or enemy);
- internal threat (environment);
- mission objectives (combat, other emergency, or routine);
- ventilation objectives (capacity needed to provide oxygen, to control temperature, or to remove smoke, humidity or gases in a relatively safe and timely fashion);
- manpower and skill available; and
- energy source to drive option.

Options for providing ventilation include (while all may not be available, here is a range of options)

- contain problem area until later;
- restore installed ventilation;
- reconfigure installed ventilation to serve new needs;
- utilize natural draft ventilation and/or augment with ship's relative wind; and
- utilize portable forced ventilators
  - \* A3/4T air-turbine driver blower (ATB)
  - \* O 1/2 axial-type blower (Electric Red Devil)
  - \* Water Motor Fan (WMF).

Each of these options come at a relative cost for time to rig, manpower required, energy source, and safety.

### **Examples of Tactical Options**

#### **Non-emergency Situations**

If there is no other casualty other than loss of installed ventilation, no time constraints, or no increased threat and with proper skills, manpower, tools and material, permanent restoration is the best selection. If permanent restoration is not possible and temporary ventilation must be provided, the choice of options is a matter of convenience and availability. Given that no installed ventilation exists such as in "Gas Freeing" with a space with oxygen deficiency, toxic gases, or explosive vapors, the main factors to consider become

1. availability and capacity of equipment;
2. available energy source to drive equipment at required location; and
3. safety characteristics of equipment.

Assuming all options are available in adequate quantity, the CFM required to gas free and maintain that state should be determined (see NSTM 074, Volume 3, Gas Free Engineering). The location of the nearest energy source to drive equipment should be identified. Electrical has the greatest distribution, followed by fire main, then the ship's service air.

The safety features of equipment determine, through a process of elimination, the best choice for dealing with specific atmospheres. For example, oxygen deficient or toxic atmospheres would be appropriately dealt with by any of the portable equipment. The selection of equipment becomes a matter of convenience. Explosive atmospheres require the use of "explosion proof" equipment. This eliminates the electric "Red Devil" (Ref. C12), leaving the Air-Turbine Blower (ATB) or WMF. If the capacity of either will meet the need, the choice would probably be the ATB since it would be easier to rig air hose than water supply and discharge hoses. Either blower would suffice.

### Emergency Situations

"Emergency Conditions" exist when the ship goes to "Condition I," General Quarters (GQ). At that time, the responsibility for controlling the ventilation shifts from a few highly skilled personnel to more personnel with less skill and training. While "safety" is never absolute, under emergency conditions it becomes much more relative. Probabilities for greater dangers rapidly increase if minor chances are not taken in a timely fashion.

The tactical situation relates to the perspective of the Damage Control challenge. It is assumed that Ship Command has other tactical concerns and priorities yet has assigned control of the fire as highest priority for Damage Control. In the past, desmoking was a post-fire event and not as time-critical. It is now recognized that desmoking during a fire can significantly improve firefighting.

Different safety considerations now come into play. Heat, smoke, and possibly toxic or explosive atmospheres could be generated which present new challenges and considerations in selecting desmoking equipment. Under conditions where there is heat and dense smoke, there is a possibility of explosive and toxic gases. There is currently no device or procedure for confidently confirming the presence of these gases, so one must assume they are present. The normal reluctance to use the Red Devil in explosive atmospheres and the threat of high heat and moisture influence its selection. The relatively small number of ships service air outlets as compared to fire plugs would necessitate long air hose runs traversing closures. The possibility of rupturing a compressed air line near a fire also influences the selection of the ATB. The difficulty in rigging and tending hoses for the WMF influences the decision to select the WMF.

Given a casualty situation with fire and smoke, several other conditions may exist: no electrical power available, no compressed air available, and/or no fire main pressure available.

## EXAMPLE DAMAGE CONTROL SITUATION

### Damage Control Scenario

The decision on which procedure to use and how to route equipment will depend on many considerations beyond those previously discussed. The decision will be made at the lowest level unless otherwise directed by higher authority (the C.O., the DCA, the Repair Party Officer, the On-scene Leader, or the Desmoking Team Leader). Communicating the plan allows consideration and reflection of the Command or Damage Control tactical concerns such as

1. higher priority need for available assets (personnel, water pressure, hoses, etc.);
2. increased threat of external or internal source of flooding via duct or hose routes (ship's watertight integrity);
3. increased threat of ship chemical contamination (gas tight envelope);
4. location of accesses which could allow proper air flow patterns to sweep smoke and assure it is not reingested; and
5. maneuvering requirements (relative wind, course, and speed).

For the scenario considered here, assume the ship is "Dead in the Water" with all installed distributive systems down. Portable equipment remain functional so the P-250 is rigged to provide water pressure for firefighting.

### Tactical Options

Assume that firefighting is the top priority, and it may be desirable to simultaneously control smoke. Tactical options where decisions must be made may encompass the following:

1. fight fire,
2. control smoke,
  - a. do not use smoke curtains (Zebra only),
  - b. use smoke curtains (with Zebra),
    - (1) do not use concurrent desmoking,
    - (2) use concurrent desmoking with exhaust venting (negative pressure),
      - (a) from compartment with one access,
      - (b) from compartment with more than one access, and
      - (c) select desmoking equipment.

Positive pressure venting with and without integral water misting are also potential options. Since there are limited data on these approaches, they are not considered here.

## Select Desmoking Equipment

For any given damage control scenarios, ventilation may be affected:

1. naturally,
2. via installed ventilation systems,
3. using the Red Devil Blower,
4. using the Air Turbine Blower, and
5. using the Water Motor Fan.

As a result of the fire testing described in this report, increased options and capabilities are now available using the WMF. It extends the flexibility and adaptability (survivability design features) of ventilation capability since it uses a different power source. Sufficient water pressure from any source at multiple locations through the ship may be used. Based on the test data, the WMF has increased air moving capacities.

The WMF has different support requirements:

1. water hoses needed for supply and discharge,
2. hose tending necessary,
3. ground lead required under certain circumstances,
4. if the 10 in. air suction and discharge ducts are not made the same and if other two blowers are not converted to 10 in. from 8 in., there will be logistic support additions for training, supply, and manufacturing.
5. water supply pressure and discharge must be monitored to assure there is no undue flooding.

Other advantages of the WMF include the following.

1. Ability to operate under extreme heat—the WMF suffered no significant damage when subjected to temperatures as high as 225°C (437°F). The electric blower would not be expected to continue operation under these conditions. With these heat conditions, the air hose supplying pneumatic blowers may rupture, potentially contributing pressurized air to the fire. During extreme challenges (e.g., heat stress test described in report), the current WMF ducts are expected to fail
2. With adequate pressure and hose tending, the WMF may be used against any head pressure reasonably expected on a ship.
3. Any pumping source with adequate flow and pressure may be used to supply the WMF.

Initial charging of water hoses to and from the WMF causes a shift in its center of gravity and may cause it to tip over. Damage is unlikely, and it should continue to operate satisfactorily. As with any equipment, proper tending should avoid problems.

## Procedures

As an example, assume the Repair Party has been ordered to fight the fire and control smoke during the fire while using smoke curtains with Zebra set. The Repair Party rigs a WMF to exhaust a fire boundary area compartment which has more than one access which may be opened. The objectives of this procedure are to prevent spread of smoke, reduce smoke at fire boundary, and improve tenability at fire boundary by reducing temperature and steam while preventing additional oxygen to the fire.

It is assumed that the area has become smoke logged after the fire started, but before Zebra was set or that area became smoke or steam logged due to the heat from the fire and firefighting operations.

The Desmoking Team and Fire Boundary Personnel work together on this procedure.

### Fire Boundary Personnel

Fire boundary personnel are first to arrive on scene at the fire boundary. They would do the following.

1. Inspect the area to locate hazards and to ensure intactness of hot side fire boundaries at their location. This inspection may require the use of the NFTI.
2. Alert the desmoking team to conditions, and should an opening exist which would allow air flow to the fire, take action to secure the area.
3. Assist the desmoking team in rigging or adjusting smoke curtains and WMF ducts.
4. Perform fire boundary duties.

### Desmoking Team

Once assigned to an area to desmoke, the desmoking team would plan, rig, and position their equipment such that water hose runs and air ducts are optimized in terms of vent hose routing and water hose line tending. They would do the following.

1. Determine the accessibility to the area. If atmospheric conditions dictate augmented clothing or breathing protection, they would take necessary precautions.
2. Identify access from which to take suction with WMF or duct. If smoke curtains are not already rigged, they would request fire boundary personnel to assist in rigging.

3. Identify access from which to draw clean air into smoke logged compartment. If multiple accesses exist, they would select the one which will best sweep smoke from the compartment. If a door exists at that location and it is controllable, it may be used to adjust air flow. If no adjustable closure is on the air access, the smoke curtain would be rigged for later adjustment.
4. Position the WMF at desired location, preferably on the weather deck. This should minimize the amount of hose and duct required. Alternately, below decks, discharge ducts rigged to weather or controlled-installed vent ducts which go to weather would be used.
5. Identify the most appropriate 1.5 in. water supply (from P-250 or jumpered fire main) and attach minimum number of hose lengths necessary to reach position where WMF will be located. They would lay the hose out for later attachment to the WMF.
6. Identify the most appropriate location to dispose of water from WMF discharge, and layout and secure minimum number of hose lengths necessary to reach the position where the WMF will be located. This may be to a weather deck or directly over the side, to an "overboard discharge" on the DC deck (this may require a 1.5 in. female to 2.5 in. male coupling), to a lower compartment with working installed drainage system (e.g., tank, machinery room bilge), or the water may be temporarily used to flood a deck above a fire to assist in setting a fire boundary.
7. Connect the water supply hose to a 1.5 in. female fitting on the WMF and connect the water discharge hose to a 1.5 in. male fitting on the WMF.
8. Connect a 10 in. air discharge duct (single stitch reinforcement over internal wire) to the end of the WMF which has the arrow pointing to it (if a discharge duct is required). They would connect the 10 in. air suction duct (double stitch reinforcement over internal wire) to the inlet side of WMF.
9. Attach the WMF ground strap to bare metal of ship structure, piping, or machinery.

**NOTE:** The exact order in which this procedure takes place is unimportant and may occur as convenient to minimize personal exposure. The final action of the Desmoking Team prior to starting the WMF held until last to minimize smoke migration through the access would be to conduct #10.

10. Position and secure the inlet side of the suction duct within the smoke logged compartment at the overhead (if possible). Otherwise, the duct would be inserted through the doorway top against the lintel and the smoke curtain tightened around the duct. The curtain would be sealed all around

the door. If suction is being taken through a hatch rather than a door, the duct should only be inserted down through the smoke blanket a few inches.

**CAUTION:** Hoses and ducts should be routed such that they present minimum trip hazard or obstruction to personnel movement (drape to the side of ladders and passages, and consider going through hatch (if possible) rather than scuttle.

11. Alert fire boundary personnel that the WMF is about to be started and that they should maintain smoke curtain or blanket seals.
12. The desmoking team leader will position himself/herself at the clean side of the access from which clean air is to be drawn into the smoke logged compartment. He/she would then order the WMF started. As the WMF comes to speed, he/she would open the bottom of the curtain until smoke just starts to wisp toward him/her and then close the curtain as little as possible to maintain his/her area smoke-free. If a closure is available, the same principle would be used.
13. When ordered, the water supply plugman will slowly (but fully, unless told to stop) open the water supply to the WMF while one desmoking team member tends the WMF, hoses, and ducts to assure proper operation. When the WMF has come to full speed (steady sound of motor whine), periodic tending should suffice.



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